ESSAYS IN INTERNATIONAL TRADE

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A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Economics – Doctor of Philosophy

2022

ABSTRACT

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In chapter 1, I investigate how resource reallocation can affect the change of trade patterns and welfare effect of trade. Specifically, trade liberalization can lead to a surge in the trade of intermediate goods. Increased accessibility to the critical intermediate goods through international trade can create an opportunity to initiate the expansion of capital-intensive industries, which can be referred to as specialization dynamics for developing countries. For this to occur, domestic resources must be reallocated toward high productivity sectors. In this paper, I capture the reallocation frictions in the labor market with sectoral wage differentials. A general equilibrium analysis explains the relationship between specialization dynamics and resource reallocation. I find that higher distortions in the skilled labor market negatively affect the productivity gain in the capital-intensive sector. This effect lowers overall welfare gains from trade for the countries with higher labor market distortions.

In chapter 2, I deepen the argument in chapter 1 by extending the model to dynamic structural model. Sluggish labor market response to trade liberalization can reduce the welfare gains from trade by impeding resource reallocation. I estimate sectoral labor switching costs for 30 countries in a dynamic discrete choice problem to derive welfare implications of labor market rigidity through comparative cross-country analysis. On average, workers have to give up approximately 4-years of income to switch to another sector. Compared with labor market flexibility measures, labor switching costs are low when the country has a flexible labor market and vice versa. In addition, I embed the switching cost estimates into a dynamic multi-country, multi-sector Eaton and Kortum model. In a counterfactual trade liberalization simulation with a 20% drop in trade costs, high switching costs lead to a slower response in the labor market, which in turn, negatively affect a country's ability to achieve welfare gains from trade.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to my advisor, Professor Carl Davidson, for his encouragement, support, and guidance. I also want to thank Professor Steven Matusz. Regular research meetings with Professors Davidson and Matusz nurture me as a Ph.D. researcher. Those meetings will be one the most memorable moments in my Ph.D. program. Lastly, I thank Professor Chun Zhu for initiating my research idea. I could not have completed the dissertation without the support and patience of my committee members.

Doing a Ph.D. during the pandemic has been challenging, and I owe a lot to many. Most of all, I am deeply grateful to my family for their continuous support and love. My friends do not let me feel isolated and give me cheering words whenever I am in a slump.

I want to honor every help I got from my committee, family, and friends for this achievement.

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CHAPTER 1

SPECIALIZATION DYNAMICS, RESOURCE REALLOCATION, AND GAINS FROM TRADE

1.1 Introduction

Even when countries face common changes in external environments (such as globalization), their fortunes can vary significantly depending on how they respond to the changes. Some countries may take advantage of new opportunities and achieve significant welfare gains, while others may face obstacles that keep them from achieving similar gains. In line with this notion, I focus on how countries respond to trade liberalization, focusing on the role of labor market distortions. In particular, I aim to examine how the level of labor market distortions affects the welfare gains from trade.

The welfare effects of international trade have been studied from many different angles. Among those, the well-known work by Arkolakis et al. (2012) has been commonly used in a quantitative general equilibrium trade model to gauge the gains from trade. In that paper, the authors find a general formula (the ACR formula) that can be applied to various models. The main advantage of this method is that the formula relies on only two sufficient statistics - the trade elasticity parameters and the change in the domestic consumption shares. However, to get a more detailed picture of the welfare effects of international trade, it is worthwhile to investigate the mechanism by which those two variables are determined and affected in response to trade liberalization.

One of the distinguishing features of recent trade, thus necessary to be reflected in the model, is the surge of trade in intermediate goods. Johnson (2014) provides evidence that the proportion of intermediate goods trade has been rising since the foundation of the World Trade Organization (WTO) and documents that such trade now accounts for approximately 66% of total international trade flows. In addition, Timmer et al. (2014) find that the trade of intermediates is biased toward capital goods in that the share of capital inputs and the share of skilled labor are increasing.

Since capital goods are usually essential inputs in the high-tech industry, these changes create new opportunities for countries to seek higher welfare gains by importing key inputs to expand production in specific sectors.

Particularly, developing countries can produce high-tech industrial goods despite their historic comparative disadvantage in the sector. For example, Lenovo, a Chinese computer firm, has grown its productivity quickly and now has a considerable market share in the U.S. computer industry. However, it would be much more difficult for Lenovo to export computers to developed countries if it could not import the most crucial intermediates for computers - Central Processing Unit (CPU) – from Intel. In a nutshell, by importing intermediates, developing countries can overcome technical bottle-necks that hinder them from shifting production away from low-level industries and initiates specialization dynamics toward capital-intensive industries.

Hanson (2012) also pointed out that increased trade in intermediates can bring significant welfare gains to middle-income countries and refers to it as specialization dynamics. Figure A.1 compares the export share of capital goods in 1995 and 2007. In many countries, the share of capital goods exported out of total export increases, consistent with the idea captured by specialization dynamics.[1]

However, the ability to take advantage of the new opportunities offered by the surge in trade in intermediaries is not automatic. Even when essential intermediates are available in the world market, a labor force with the requisite skills to use those imported intermediates is necessary to nurture and expand high-level industries. For example, Święcki (2017b) shows that domestic distortions in factor markets can have significant effects on the gains from trade by deriving a modified ACR formula in the Eaton and Kortum (2002) model with distortions. The intuitive interpretation is that the domestic resource reallocation in response to trade liberalization is a critical determinant of achieving higher welfare gains.

This paper will explore the relations between the domestic factor market distortions and welfare gains from trade. First, I captured the labor market distortions with sectoral wage differentials as

[1] Developed countries with decreased export share of capital goods - Australia, Canada, United Kingdom, and the United States, the output share of service sector increased.

in Święcki (2017b). One distinction is that I include multi-factor (skilled and unskilled labor) to distinguish the effect of reallocation friction for each type of labor. Thus, I could also reflect the capital-skill complementarity in the model in a similar way with Parro (2013). Then the wage wedges for each type of labor are embedded into a multi-sector Eaton and Kortum (2002) model with input-output linkages.

The model structure and the solution algorithm are based on the quantitative trade literature. (Costinot and Rodríguez-Clare (2014); Caliendo and Parro (2015)) At first, I express the model variable in a relative change form by employing the exact hat algebra. Then, I fit the model at the 1995 level and solve for the 2007 counterfactual outcomes. The estimated change in trade costs reflects trade liberalization between 1995 and 2007.

The quantitative analysis suggests that the initial level of distortions in the skilled labor market negatively affects the productivity gain in the capital-intensive sector. Moreover, since skilled labor is a crucial production factor in the capital-intensive sector in most countries, the distortions harm countries' capability to achieve welfare gains from trade. Compared with a counterfactual scenario without any distortions, higher wage wedges in the skilled labor market induce lower welfare gains from trade. This result contributes to a better understanding of the relationship between domestic resource reallocation friction and gains from trade.

My work can also stretch to the literature regarding structural changes such as Uy et al. (2013). They show that in the trade equilibrium, the comparative advantage sectors can expand more than the autarky level to serve the greater demand in the world market. Furthermore, they suggest that productivity gains through trade in intermediate inputs can induce industrial composition in the economy, referred to as structural change. While their work mainly focuses on the industrial response to trade liberalization, my paper studies the role of distortions in the domestic factor market to determine the industrial outcome and how it can contribute to the welfare effects of trade.

The rest of the paper is structured as follows. First, in section 1.2, the detailed feature of the model will be illustrated. Then, I will explain how I construct the data to calibrate to the model variables in section 1.3. Lastly, I will investigate the quantitative results in section 1.4.

1.2 Model

The model is based on the multi-sector and multi-factor extension of the Eaton and Kortum (2002) model. In addition, the model reflects the sectoral input-output linkage by adding composite intermediate goods as a production factor for each sector. Lastly, the model introduces capital and skill complementarity through the constant elasticity of substitution (CES) production function. The model features are pretty similar to Parro (2013).

There are N countries indexed by i or n, and three sectors indexed by l or j and J is the set of sectors such that $J \equiv \{K, NK, NT\}$ which represents capital goods(K), non-capital tradable goods(NK) - which includes both agriculture and non-capital augmented manufacturing goods, and non-tradable goods(NT), respectively. The categorization of the sectors is based on the OECD manufacturing classification. According to the OECD Structural Analysis (STAN) database, there are huge differences in capital intensity and R&D expenditure even in the manufacturing sector, so it would be appropriate to divide manufacturing into high-tech and low-tech industries. In line with this notion, the NK sector in this paper includes low and medium-level technology industries such as textile and wood products, while K industries are composed of chemicals, machinery, and automobile.

There is a unit-measure continuum of varieties in each sector. The varieties are costlessly aggregated into composite goods in each sector j. These sectoral composite goods are consumed as final goods by a representative consumer or used again as a production factor, which brings the aforementioned input-output structure to the model.

1.2.1 Consumer

A cross-sectional utility of the representative consumer in country i is written as a two-tier utility function where the outer function is Cobb-Douglas form while the inner function is CES form.

$$U(C_i^K, C_i^{NK}, C_i^{NT}) = \prod_{j \in J} (C_i^j)^{\beta_i^j} \qquad s.t. \sum_{j \in J} \beta_i^j = 1 \tag{1.1}$$

Here, C_i^j represents composite goods produced in sector j and consumed as final goods. The production part in the following section will complete a detailed structure of composite goods. If I denote the price of sector j composite goods as P_i^j, the Cobb-Douglas form of outer function of two-tier utility induces the country i's overall price index as follows:

$$P_i = \prod_{j \in J} (P_i^j / \beta_i^j)^{\beta_i^j} \tag{1.2}$$

This price index will be used to evaluate the welfare effect of trade on the representative consumer.

1.2.2 Production

The basic structure of the production is that each producer makes intermediate varieties, and those varieties are aggregated into composite goods. Since the aggregation is costless, it is sufficient to define the usual production function only over intermediate varieties, and it is redundant to define the producer of composite goods. However, I will explain composite goods first and intermediate varieties later for the expositional purpose.

Composite Good The intermediate varieties ($q_i(\omega^j)$) are aggregated into composite goods (Q_i^j) as follows:

$$Q_i^j = (\int_0^1 q_i(\omega^j)^{(\eta^j-1)/\eta^j} d\omega)^{\eta^j/(\eta^j-1)} = C_i^j + \sum_{l \in J} \int_\Omega z_i^{j,l}(\omega^l) d\omega^l$$

The first equality is the definition of the sectoral composite goods. The second inequality represents an important feature of the model. Composite goods are consumed as final goods but can also be used as production inputs to produce intermediate varieties, representing the Input-Output structure of the production. I will denote the composite goods produced in sector j and used in sector l as production inputs by $z_i^{j,l}$. The second equality which is based on the market-clearing condition for composite goods clarifies that composite goods can be consumed either as final goods

(C_i^j) or production inputs $(z_i^{j,l}(\omega^l))$.[2]

Intermediate Variety In the production of intermediate varieties, two types of labor - skill and unskilled labor are the only primary production factors. The way labor is combined with composite goods determines the feature of the production function. Specifically, a nested CES function represents the *complementarity between capital goods and skilled labor*. Recall that the capital composite goods produced in sector K used as intermediate goods to produce sector j variety $\omega^j \in [0,1]$ is denoted by $z_i^K(\omega^j)$. It is combined first with skilled labor (S):

$$h_i(\omega^j) = [[\delta_i^j]^{\frac{1}{\rho}}[z_i^K(\omega^j)]^{\frac{\rho-1}{\rho}} + [1-\delta_i^j]^{\frac{1}{\rho}}[S_i(\omega^j)^{\frac{\rho-1}{\rho}}]^{\frac{\rho}{\rho-1}}$$

The composite of capital goods and skilled labor, that is $h_i(\omega^j)$ is combined again with unskilled labor (U):

$$v_i(\omega^j) = [[\mu_i^j]^{\frac{1}{\sigma}}[U_i(\omega^j)]^{\frac{\sigma-1}{\sigma}} + [1-\mu_i^j]^{\frac{1}{\sigma}}[h_i(\omega^j)^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}}$$

Note that both aggregations feature CES form with the elasticity of substitution parameters ρ and σ. If the elasticity of substitution parameters satisfies $\sigma > \rho$, it will capture the capital-skill complementarity.

In sum, the production function of country i for variety $\omega^j \in [0,1]$ is given by:

$$q_i(\omega^j) = A_i^j[z_i^{NK}(\omega^j)]^{\gamma_i^{NK,j}}[z_i^{NT}(\omega^j)]^{\gamma_i^{NT,j}}[v_i(\omega^j)]^{1-\gamma_i^{NK,j}-\gamma_i^{NT,j}} \tag{1.3}$$

Here, $z_i^{l,j}(\omega^j)$ is the sector-l composite goods used to produce ω^j. Hereafter, I will denote it briefly as $z_i^{l,j}$ for simplicity. Since each variety is aggregated into composite goods as in the above section, and the composite goods are used again to produce varieties, this production function reflects the input-output linkage across sectors. Note that $\gamma^{l,j}$ are Cobb-Douglass parameters of each input, so it is equal to the cost-share of the production factor from sector l used in the production

[2]Here, ω^l is the index for variety which will be defined in the following subsection.

of ω^j relative to the revenue generated from ω^j. I assume that the cost-share $\gamma^{l,j}$ is the same in a given sector across all varieties, so I will suppress the notation of ω^j and denote it as $\gamma^{l,j}$.

Finally, A_i^j denotes the level of productivity following Fréchet distribution with cumulative distribution function (CDF) $F_i(A) = e^{-\lambda_i^j A^{-\theta j}}$. Here, λ is a shift parameter capturing the average productivity level, while θ is the inverse of the dispersion parameter. Lower θ means higher dispersion of productivities, and thus higher incentive of specialization.

Following the above production structure, the cost minimization problem of the intermediate variety producer can be written as:

$$\min_{S_i(\omega^j), U_i(\omega^j), \{z_i^l(\omega^j)\}_{l\in J}} \sum_{l\in J} P_i^l z_i^l(\omega^j) + w_i^{S,j} S_i(\omega^j) + w_i^{U,j} U_i(\omega^j)$$

$$\text{subject to } A_i^j [z_i^{NK}(\omega^j)]^{\gamma_i^{NK,j}} [z_i^{NT}(\omega^j)]^{\gamma_i^{NT,j}} [v_i(\omega^j)]^{1-\gamma_i^{NK,j}-\gamma_i^{NT,j}} \geq q_i(\omega^j)$$

For notational simplicity, I will define the price of $h_i(\omega^j)$ - the composite of capital and skilled labor - and the price of $v_i(\omega^j)$ - the composite of h and unskilled labor - as follows:

$$\begin{aligned} P_i^{h,j} h_i(\omega^j) &= P_i^K z_i^K(\omega^j) + w_i^{S,j} S_i(\omega^j) \\ P_i^{v,j} v_i(\omega^j) &= P_i^h h_i(\omega^j) + w_i^{U,j} U_i(\omega^j) \end{aligned}$$

Then, plugging in the first-order conditions of the cost minimization problem leads to the following expressions for the price of composite inputs.

$$\begin{aligned} P_i^{h,j} &= [\delta_i^j [P_i^K]^{1-\rho} + [1-\delta_i^j][w_i^{S,j}]^{1-\rho}]^{\frac{1}{1-\rho}} \\ P_i^{v,j} &= [\mu_i^j [w_i^{U,j}]^{1-\sigma} + [1-\mu_i^j][P_i^{h,j}]^{1-\sigma}]^{\frac{1}{1-\sigma}} \end{aligned}$$

Market Structure The intermediate variety market is perfectly competitive, thus, if the optimized cost is represented as $P_i^{NK} z_i^{NK}(\omega^j) + P_i^{NT} z_i^{NT}(\omega^j) + P_i^{v,j} v_i(\omega^j)$, it should be equal to revenue incurred from that variety ($p_i(\omega^j) q_i(\omega^j)$). By imposing $q_i(\omega^j) = 1$ and using the optimization results, I can find the price of each intermediate variety as:

$$p_i(\omega^j) = B_i^j [P_i^{NK}]^{\gamma_i^{NK,j}} [P_i^{NT}]^{\gamma_i^{NT,j}} [P_i^{v,j}]^{1-\gamma_i^{NK,j}-\gamma_i^{NT,j}} / A_i^j$$

where $B_i^j = (\gamma_i^{NK,j})^{-\gamma_i^{NK,j}}(\gamma_i^{NT,j})^{-\gamma_i^{NT,j}}(1-\gamma_i^{NK,j}-\gamma_i^{NT,j})^{-(1-\gamma_i^{NK,j}-\gamma_i^{NT,j})}$.

It would be convenient to define the *unit cost of input bundles net of productivity*:

$$c_i^j = B_i^j [P_i^{NK}]^{\gamma_i^{NK,j}} [P_i^{NT}]^{\gamma_i^{NT,j}} [P_i^{v,j}]^{1-\gamma_i^{NK,j}-\gamma_i^{NT,j}} \tag{1.4}$$

This implies that the price of each intermediate variety produced in country i can be expressed as $p_i(\omega^j) = c_i^j / A_i^j$.

1.2.3 International Trade

Trade Costs There are two kinds of costs incurred by international trade. When goods are shipped abroad (from country i to n), it will bear iceberg trade costs (Samuelson, 1954) $d_{ni} > 1$. That is, for one unit of goods to be delivered from i to n, $d_{ni} > 1$ amount of goods should be shipped, and it is unobservable part of the trade costs. The other type of cost is the observable ad-valorem tariff denoted as τ_{ni}^j. The overall trade cost is represented as $\kappa_{ni}^j = d_{ni}(1+\tau_{ni}^j)$ with $\kappa_{ii} = 1$.

Due to the trade costs, the hypothetical price[3] of intermediate variety shipped from i to n is $c_i^j \kappa_{ni}^j / A_i^j$. Each country n chooses to buy the variety ω^j from the lowest-cost source. So the realized price of intermediate goods in country n is determined as:

$$p_n(\omega^j) = \min_i \{\frac{c_i^j \kappa_{ni}^j}{A_i^j}\}.$$

Note that the price of non-tradable goods can also be represented in the same framework by imposing $d_{ni}^{NT} = \infty$. Then, $p_n(\omega^{NT}) = \min_i\{p_{ni}(\omega^{NT})\} = p_{nn}(\omega^{NT})$.

Price of Composite Goods Using the properties of Fréchet distribution, Eaton and Kortum (2002) showed that the expression for the price of composite goods under frictional trade can be

[3] Here, the reason why the price is hypothetical is that countries source intermediate goods from the minimum cost source, so whether country i will provide the good to n is not determined before the cost-minimizing sourcing decision.

obtained as:

$$P_n^j = \Psi^j (\sum_{i \in I} \lambda_i^j [c_i^j \kappa_{ni}^j]^{-\theta^j})^{-1/\theta^j} \tag{1.5}$$

where $\Psi^j \equiv \Gamma(\frac{\theta^j + 1 - \eta^j}{\theta^j})^{1/(1-\eta^j)}$ and $\Gamma(\cdot)$ is gamma function.

Gravity Equation In addition, I will denote country n's total expenditure on the sector j goods as X_n^j, and country n's total expenditure on the sector j goods sourced from country i as X_{ni}^j, respectively. Then, the expenditure shares of country n on sector-j goods sourced from country i has the meaning of the probability of importing sector j goods from country i, and it can be expressed as follows:

$$\pi_{ni}^j = \frac{X_{ni}^j}{X_n^j} = \frac{\lambda_i^j (c_i^j \kappa_{ni}^j)^{-\theta^j}}{\sum_{i \in I} \lambda_i^j [c_i^j \kappa_{ni}^j]^{-\theta^j}} \tag{1.6}$$

This equation is equivalent to the so-called gravity equation, and the denominator is the multilateral resistant term. Equation (2.9) shows that bilateral trade share is the decreasing function of exporting countries' production costs and bilateral trade costs.

1.2.4 Sectoral Labor Reallocation Friction

1.2.4.1 Market distortions and wage differentials

Note that wages are determined in the production function and thus in the cost function in type-specific and sector-specific ways. It is a crucial feature to capture resource reallocation problems in the model. Labors are divided into skilled and unskilled labor, but conditional on the given type, each labor is assumed to be homogeneous. It implies that if the labor market is frictionless, wages for each type of labor should be equalized across sectors in a given country. In addition, the cost minimization problem of each variety producing firm implies that the wages paid to labor are equal to the value of the marginal product of labor (VMPL). In other words, the existence of wage differentials across sectors reflects the possibility of the sectoral allocation distortions represented by the differentials of VMPL across sectors within a country. [4]

The wage differentials across sectors are a source of cost differentials for the producers. Specifically, the relative wage differentials can be summarized in a similar way as in Święcki (2017b):

$$\xi_i^{S,j} \equiv \frac{w_i^{S,j}}{w_i^{S,NK}}, \qquad \xi_i^{U,j} \equiv \frac{w_i^{U,j}}{w_i^{U,NK}} \tag{1.7}$$

By normalizing sectoral wages with the wage level in the non-capital sector, I can introduce the parameter ξ, so-called wage wedges, to capture the sectoral wage differentials. One advantage of this parameterization is that ξ can be matched with data and treated as an exogenous variable in solving the model and conducting counterfactual analysis.

This way of modeling wage differentials has been developed mainly in trade and growth literature. Tombe (2015) focuses on the productivity differences between the agriculture sector and the rest of the economy in the developing countries. Tombe (2015) finds evidence that international trade can increase the level of labor market distortions in terms of wage wedges and interpret it as the reason why developing countries stay as agriculture dominating economies based on the notion that wage wedge captures cost differentials of producers. Święcki (2017b) employs similar wage wedge parameters in a multi-sector Eaton-Kortum model and derives the relation between wage wedges and gains from trade. Since international trade induces the reallocation of production factors from importing sectors toward exporting sectors and it is a crucial channel how trade liberalization brings welfare gains, the existence of resource reallocation friction represented by wage differentials has notable effects on the gains from trade. Following this convention, I will interpret wage wedges as labor market distortions and explore how wage wedges are related to the change of specialization pattern and the gains from trade.

[4] Note that sectoral wage equalization is one of the common outcome in standard Eaton and Kortum (2002) model such as Parro (2013) and Caliendo and Parro (2015).

1.2.4.2 Issues in wage wedge modelling

Despite the main advantage of empirical availability, the aforementioned approach to the wage differentials has an explicit limitation: it is silent about the source of sectoral wage differentials. Thus, it is worthwhile to briefly review more micro-founded explanations on the sectoral wage differentials for future work.

One way of modeling sectoral reallocation friction problem is by assuming sector specificity of skills that production factors have. In this case, production factors cannot move across sectors due to the specificity of skills, resulting in lower welfare gains than in the perfect mobility case. Levchenko and Zhang (2013) applies this approach in the similar Eaton-Kortum model with labor and capital as production factors. Their finding is that labor and capital mobility are complements, so immobility of one of the factors leads to a severe welfare loss.

However, the Levchenko and Zhang (2013) approach also has limitations in that it only assumes the perfect sector specificity of skills which in turn the perfectly immobile production factors across sectors. To implement an imperfectly mobile case, the structure transition matrix with dimension $(J \times J)$ should be included in the model, and then the demand for the data to estimate the matrix gets much higher. Recently, Caliendo et al. (2019) try to implement the switching mechanism into the Eaton-Kortum model based on the dynamic discrete choice problem of workers introduced in Artuç et al. (2010) to measure the welfare effects of the trade with China on the U.S. economy. However, it requires sectoral mobility data. As the demand for the data is surging, the approach is more appropriate for analyzing a specific country's response to the trade shock rather than a cross-country comparison analysis as in this paper.

An alternative way is to attribute the wage differentials to the unobserved productivity of the labor force. For example, Lagakos and Waugh (2013) introduces the sorting mechanism of unobserved productivity, which results in the sectoral wage differentials across sectors. However, for a similar reason as in Caliendo et al. (2019), it requires data on workers who switch sectors to identify the switching mechanism, which makes it harder to be applied in cross-country comparison analysis.

In summary, the attribution of the whole wage differentials to the labor market distortions, as in my paper, can be problematic since it lacks a micro foundation to result in the overestimation of the extent of distortions. However, it has the advantage of empirical availability, so I will employ this method in this paper and leave the further extension of the method for future research.

1.2.5 Equilibrium

Labor Market The gross output of sector j in country i is denoted by $Y_i^j = P_i^j Q_i^j$. Since two types of labor are the only primary production factors of the economy, the payment to the factors in each sector should satisfy the following equations:

$$w_i^{S,j} S_i^j = \xi_i^{S,j} w_i^{S,NK} S_i^j = \gamma_i^{S,j} Y_i^j \quad \forall j \in J \tag{1.8}$$

$$w_i^{U,j} U_i^j = \xi_i^{U,j} w_i^{U,NK} U_i^j = \gamma_i^{U,j} Y_i^j \quad \forall j \in J$$

where $\gamma_i^{S,j}$ is defined as $\frac{w_i^{S,j} S_i^j}{P_i^j Q_i^j}$ which means the cost share of skilled labor out of total revenue. Specifically, the cost minimization problem implies:

$$\begin{aligned}
\gamma_i^{S,j} &= [1-\gamma_i^{NK,j}-\gamma_i^{NT,j}][1+\frac{\mu_i^j}{1-\mu_i^j}[\frac{P_i^{h,j}}{w_i^{U,j}}]^{\sigma-1}]^{-1}[1+\frac{\delta_i^j}{1-\delta_i^j}[\frac{w_i^{S,j}}{P_i^K}]^{\rho-1}]^{-1} \\
\gamma_i^{U,j} &= [1-\gamma_i^{NK,j}-\gamma_i^{NT,j}][1+\frac{1-\mu_i^j}{\mu_i^j}[\frac{w_i^{U,j}}{P_i^{h,j}}]^{\sigma-1}]^{-1}
\end{aligned}$$

Recall that in equation (1.3), two types of labor are the only primary production factors. Thus, the sum of $\gamma_i^{S,j}$ and $\gamma_i^{U,j}$ means the value-added share of sector j out of total output.[5] For notational simplicity, I will also define the value-added in each sector as the sum of payments to primary factors:

$$V_i^j = w_i^{S,j} S_i^j + w_i^{U,j} U_i^j, \qquad V_i = \sum_{j \in J} V_i^j$$

Lastly, sectoral labor shares can be obtained from labor market equilibrium conditions.

$$s_i^j \equiv \frac{S_i^j}{S_i} = \frac{S_i^j}{S_i^{NK}+S_i^K+S_i^{NT}} = \left(1+\frac{Y_i^K \gamma_i^{S,K}}{\xi_i^{S,K} Y_i^j \gamma_i^{S,j}}+\frac{Y_i^{NT}\gamma_i^{S,NT}}{\xi_i^{S,NT} Y_i^j \gamma_i^{S,j}}\right)^{-1}$$

[5] In equation (1.3) cost shares for other composite goods are defined, so $\gamma_i^{S,j}+\gamma_i^{U,j}+\sum_l \gamma_i^{l,j} \equiv 1$

This result is intuitive. Suppose the wage in the capital sector increases relative to the non-capital sector, which is represented by the increase of $\xi_i^{S,K}$, then the labor share in the non-capital sector increases. Higher wage in the capital sector means higher factor costs in the capital sector, which lowers labor share in the sector. The sectoral labor share will be used to evaluate the welfare effects of trade in the later section.

Goods Market Define X_i^j as the total expenditure in country i for the sector j goods. Since every country can sell its products not only to its domestic market but also to foreign markets, the gross sectoral products ($Y_i^j = P_i^j Q_i^j$) are equal to the expenditures in the world market net of trade costs:

$$Y_i^j = \sum_{n=1}^{N} \frac{\pi_{ni}^j}{1+\tau_{ni}^j} X_n^j \tag{1.9}$$

where total expenditures in country n for sector j goods are represented as:

$$X_n^j = \beta_n^j I_n + \sum_{l \in J} \gamma_n^{j,l} Y_n^l \tag{1.10}$$

$$I_n = \sum_{j \in J} V_n^j + D_n + \sum_{j \in J} \sum_{i=1}^{I} \tau_{ni}^j X_n^j \frac{\pi_{ni}^j}{1+\tau_{ni}^j}$$

Recall that β_i^j is the final consumption share from Cobb-Douglas preference. Here, D_n trade deficit of country n, and the last term is tariff revenue. From equation (1.10) it is clear again that the sectoral composite output is consumed as final goods (first part of (1.10)) and intermediate inputs for other sectors production (second part of (1.10)).

Trade Balance Since the model is static, the trade balance condition can be written as:

$$\sum_{j \in J} \sum_{n=1}^{I} \frac{\pi_{in}^j}{1+\tau_{in}^j} X_i^j - D_i = \sum_{j \in J} \sum_{n=1}^{I} \frac{\pi_{ni}^j}{1+\tau_{ni}^j} X_n^j \tag{1.11}$$

The left-hand side is the total expenditure in country i, while the right-hand side is the total revenue earned from selling to the world market.

Definition 1 Equilibrium of the model is defined as wages $(w^{S,NK}, w^{U,NK})$ for production factors and price of composite goods $(P^j,\ \forall j \in J)$ satisfying equations (1.4), (2.8), (2.9), (1.8), (1.9), (1.10) and (1.11) for given consumption (β) and production parameters (input shares: γ, and elasticity of substitution parameters: ρ and σ), trade costs(κ), and wage wedges(ξ).

1.2.6 Equilibrium in Relative Changes

Instead of solving the model in an absolute term as in *Definition 1*, I followed Dekle et al. (2007) to express the model as relative changes. The main purpose of employing the method is to conduct counterfactual analysis by reducing the number of parameters that should be estimated. For any variable x, let me define $\hat{x} \equiv x'/x$, that is proportional change (x' is the value of x in new equilibrium). Then, the aforementioned equilibrium conditions can be rewritten as:

Cost of input bundles

$$\hat{c}_i^j = [\hat{P}_i^{NK}]^{\gamma_i^{NK,j}} [\hat{P}_i^{NT}]^{\gamma_i^{NT,j}} [\hat{P}_i^{v,j}]^{1-\gamma_i^{NK,j}-\gamma_i^{NT,j}} \tag{1.12}$$

$$\begin{aligned} where\ \hat{P}_i^{v,j} &= [1-\gamma_i^{NK,j}-\gamma_i^{NT,j}]^{\frac{-1}{1-\sigma}}[\gamma_i^{U,j}[\hat{\xi}_i^{U,j}\hat{w}_i^{U,NK}]^{1-\sigma}+[\gamma_i^{S,j}+\gamma_i^{K,j}][\hat{P}_i^{h,j}]^{1-\sigma}]^{\frac{1}{1-\sigma}} \\ \hat{P}_i^{h,j} &= [\gamma_i^{S,j}+\gamma_i^{K,j}]^{\frac{-1}{1-\rho}}[\gamma_i^{K,j}[\hat{P}_i^{K}]^{1-\rho}+\gamma_i^{S,j}[\hat{\xi}_i^{S,j}\hat{w}_i^{S,NK}]^{1-\rho}]^{\frac{1}{1-\rho}} \end{aligned}$$

Composite Goods Price

$$\hat{P}_i^j = [\sum_{n=1}^{N} \pi_{in}^j (\hat{c}_n^j \hat{\kappa}_{in}^j)^{-\theta^j} \hat{\lambda}_n^j]^{-\frac{1}{\theta^j}} \tag{1.13}$$

Gravity Equation

$$\hat{\pi}_{in}^j = [\frac{\hat{c}_n^j \hat{\kappa}_{in}^j}{\hat{P}_i^j}]^{-\theta^j} \hat{\lambda}_n^j \tag{1.14}$$

Labor Market

$$\sum_{j\in J} w_i^{S,NK} \hat{w}_i^{S,NK} \xi_i^{S,j} \hat{\xi}_i^{S,j} S_i^j \hat{S}_i^j = \sum_{j\in J} \gamma_i^{S,j'} \sum_{n=1}^{N} \frac{\pi_{in}^{j'}}{1+\tau_{in}^{j'}} X_n^{j'} \tag{1.15}$$

Goods Market

$$X_i^{j'} = \beta_i^j I_i' + \sum_{j \in J} \gamma_i^{S,j'} \sum_{n=1}^{N} \frac{\pi_{ni}^{j'}}{1+\tau_{ni}^{j'}} X_n^{j'} \tag{1.16}$$

$$\begin{aligned}
with\ \gamma_n^{S,j'} &= [1-\gamma_n^{NK,j}-\gamma_n^{NT,j}][1+\frac{\gamma_n^{U,j}}{\gamma_n^{S,j}+\gamma_n^{K,j}}[\frac{\hat{P}_n^{h,j}}{\hat{\xi}_i^{U,j}\hat{w}_n^{U,NK}}]^{\sigma-1}]^{-1}[1+\frac{\gamma_n^{K,j}}{\gamma_n^{S,j}}[\hat{\xi}_i^{S,j}\frac{\hat{w}_n^{S,NK}}{\hat{P}_n^K}]^{\rho-1}]^{-1} \\
\gamma_n^{U,j'} &= [1-\gamma_n^{NK,j}-\gamma_n^{NT,j}][1+\frac{\gamma_n^{K,j}+\gamma_n^{S,j}}{\gamma_n^{U,j}}[\frac{\hat{\xi}_i^{U,j}\hat{w}_n^{U,NK}}{\hat{P}_n^{h,j}}]^{\sigma-1}]^{-1} \\
I_i' &= \sum_{j \in J} V_i^{j'} + D_i' + \sum_{j \in J} X_i^{j'}[1-\sum_{n=1}^{N}\frac{\pi_{in}^{j'}}{1+\tau_{in}^{j'}}]
\end{aligned}$$

Trade Balance

$$\sum_{j \in J}\sum_{n=1}^{N} \frac{\pi_{in}^{j'}}{1+\tau_{in}^{j'}} X_i^{j'} - D_i' = \sum_{j \in J}\sum_{n=1}^{N} \frac{\pi_{ni}^{j'}}{1+\tau_{ni}^{j'}} X_n^{j'} \tag{1.17}$$

Definition 2 Equilibrium of the model in terms of relative change is defined as change of wages ($\hat{w}^{S,NK}, \hat{w}^{U,NK}$) for production factors and the change of price of composite goods ($\hat{P}^j$, $\forall j \in J$) satisfying equations (1.12), (1.13), (1.14), (1.15), (1.16) and (1.17) for given consumption (β) and production parameters (input shares: γ, and elasticity of substitution parameters: ρ and σ), the change of trade costs ($\hat{\kappa}$), and the change of wage wedges ($\hat{\xi}$). [6]

1.2.7 Specialization Dynamics

Recall that the production of each variety requires two types of labor and intermediate inputs. Thus, along with technology, both prices of skilled and unskilled labor and prices of inputs will determine the comparative advantages of each country and trade flows. Even when there are many countries and many goods, Balassa (1965) suggested the idea that the observed pattern of trade can be used to infer observable differences in relative comparative advantage, so-called revealed comparative advantages.

[6]The reason why equilibrium is defined for a given $\hat{\xi}$ rather than ξ is that $w_i^{S,NK}\xi_i^{S,j}S_i^j$ is equal to the value-added generated by skilled labor which can be matched with data, so $\xi_i^{S,j}$ does not play a role by itself in the model solving algorithm. More details are explained in the data section

From the gravity equation (2.9), the following can be derived:

$$\frac{\pi_{ni}^j}{\pi_{nn}^j} = \frac{\frac{X_{ni}^j}{X_n^j}}{\frac{X_{nn}^j}{X_n^j}} = \frac{X_{ni}^j}{X_{nn}^j} = \frac{\lambda_i^j (c_i^j \kappa_{ni}^j)^{-\theta^j}}{\lambda_n^j (c_n^j)^{-\theta^j}} \tag{2.9-1}$$

In addition, the log-difference of the above equation is:

$$\log(\frac{X_{ni}^j}{X_{nn}^j}) = \log(\lambda_i^j (c_i^j)^{-\theta^j}) - \log(\lambda_n^j (c_n^j)^{-\theta^j}) - \theta^j \log \kappa_{ni}^j \tag{2.9-2}$$

It implies that when the exporting country i's productivity in sector j (λ_i^n) is high, then i's market share increases in country n, while the importing country n's productivity in the same sector (λ_n^j) has a negative effect to the market share of i's. Therefore, depending on the relative productivity, the surge in the trade of capital-intensive intermediate goods can create an opportunity to initiate the expansion of capital-intensive industries for developing countries, that is, specialization dynamics.

However, as derived in equation (1.4), the unit cost is a function not only of intermediate inputs but also of sectoral wages. Thus, if the wage wedge is high in the capital sector relative to other sectors, it will increase the cost of production factors and eventually harm the ability to export in the capital sector. This observation will be linked with gains from trade in the next section.

1.2.8 Welfare Effects of Trade

Before diving into the quantitative analysis, it is worth deriving the welfare measure with model variables. To avoid unnecessary complexity of the CES production function, the following analytic derivation is based on the simplified version of the model, where there is only one type of labor, and the production function is a simple Cobb-Douglas form. In this simplified model, the change in real wage can be expressed as the function of the change of domestic expenditure share($\hat{\pi}_{nn}^j$) and the changes in sectoral prices($\hat{P}_n^j$).

$$\ln\frac{\hat{\xi}_n^j \hat{w}_n^{NK}}{\hat{P}_n} = -\sum_{j=1}^{J} \frac{\beta_n^j}{\theta^j} \ln\hat{\pi}_{nn}^j - \sum_{j=1}^{J} \frac{\beta_n^j}{\theta^j} \frac{1-\gamma_n^{L,j}}{\gamma_n^{L,j}} \ln\hat{\pi}_{nn}^j - \sum_{j=1}^{J} \frac{\beta_n^j}{\gamma_n^{L,j}} \ln \prod_{k=1}^{J} (\hat{P}_n^k / \hat{P}_n^j)^{\gamma_n^{k,j}}$$

To investigate the meaning of each term, consider the case where $\gamma^{L,j} = 1$. It means that labor is the only production factor for intermediate variety. In this case, the last two terms get zero, and the welfare effects would be summarized only by the first term. By the assumption, this term only reflects the welfare effects of final goods consumption since composite goods are not used as intermediate inputs, so the input-output linkage disappears. Intuitively, the welfare effects are larger when the domestic expenditure share($\hat{\pi}_{nn}^{j}$) gets lower. In addition, the welfare effects are negatively related to the inverse of the productivity dispersion parameter(θ^{j}); that is, when the productivity dispersion is more significant, then the welfare effects are higher. It can be interpreted as when the sector is heterogeneous, then importing goods from foreign producers with higher productivity gets beneficial.

The interpretation for the second term is available by assuming $\gamma^{L,j} \neq 1$ and $\gamma^{j,j} = 1 - \gamma^{L,j}$. It is the case when composite goods are used as inputs, but composite goods only from their own industry are used. Thus, it can be interpreted as an intermediate goods effect, and this effect is large when labor cost share($\gamma^{L,j}$) is lower.

The most general case is when there are no such restrictions as above. Then, as explained in the production function section, input-output linkage across sectors is fully reflected. The sectoral linkage effects on the change of real wages are expressed as $\prod_{k=1}^{J}(\hat{P}_{n}^{k}/\hat{P}_{n}^{j})^{\gamma_{n}^{k,j}}$ in the last term. The change in the price of composite goods in other sectors also affects the change in welfare, and the effects are larger when the cost share of input is large.

Lastly, the change of real GDP in country n can be represented as:

$$\hat{Y}_{n} = \sum_{j \in \{K,NK,NT\}} \frac{\hat{w}_{n}^{j}}{\hat{P}_{n}^{j}} \hat{l}_{n}^{j} y_{n}^{j} \tag{1.18}$$

where l_{n}^{j} is the labor share of sector j as in the previous section, and y_{n}^{j} is the sectoral output share. The following hypothetical example can help understand the welfare measure's implication. If wage wedges are high in the capital sector, it will lower the labor share of the capital sector, as I have shown in the labor share equation. In addition, the higher cost of labor in the capital sector will harm the (revealed) comparative advantages of the sector, so eventually, the output share will also decrease. Since higher wages in the capital sector imply higher marginal labor productivity, the decrease of labor and output share in the higher productivity sector will decrease welfare. This interpretation is consistent with Tombe (2015) in that aggregate productivity is dependent on the sectoral labor allocations in distorted labor markets.

1.3 Taking the Model to the Data

This section will describe how the data are matched with the model to solve it. In the specification, I included data from 19 countries and the rest of the world. The number of sectors is three, as congruent with the model. The initial year matched with the model is 1995 and the end of the year compared with the model solution is 2007.

1.3.1 Variables Matched with the Data

Trade Flows and Shares For the trade flows data, I used World Input-Output Database (WIOD) release 2013 with industry code ISIC rev.3. I followed the similar way described in Timmer et al. (2015) to construct the export and import data using the world input-output table database. Firstly, I calculated the domestic expenditure (X_{nn}^{j}) as the difference between the value of gross output and the value of total export of the sector. Then, the total expenditure of the sector (X_{n}^{j}) is the sum of the domestic expenditure and total import of the sector j goods. As derived in the equation (2.9), total expenditure is used as a denominator to calculate the trade shares. For the non-tradable sectors, by definition, trade flows are set to 0.

Input Cost Shares The input share variables ($\gamma_n^K, \gamma_n^{NK}, \gamma_n^{NT}$) are also computed using the world input-output tables. Firstly, the sector's gross output value is treated as the gross revenue, thus as the denominator. Then, the value of the total use of the sector j goods as an intermediate input is used to calculate the share of each intermediate input.

For shares of labor inputs (γ_n^S, γ_n^U), I use the Socio-Economic Accounts (SEA) provided as well by WIOD. SEA contains data on gross output and labor compensations. Further, the labor forces are divided into three types - High skilled, Medium skilled, and Low skilled. I combine medium-skilled and low-skilled labor into unskilled labor in the model, while high-skilled labor remains skilled labor.[7] Then, using the compensation proportion variable in the data, I compute the value-added generated by each type of labor. γ_n^S and γ_n^U are shares of those value-added relative to the gross output in the sector.

Tariffs I used Most Favoured Nation (MFN) tariff data sourced from United Nations Statistical Division - Trade Analysis and Information System (UNSTAD - TRAINS). The product level of tariff data are averaged to the sectoral level using the bilateral trade flows as weights.

Wage Wedges Recall that wage wedge is defined as equation (1.7). In terms of model variables and parameters, the wage wedge for each type of labor should satisfy the following relations:

$$\xi_i^{S,j} = \frac{\frac{\gamma_i^{S,j}}{\gamma_i^{S,j}+\gamma_i^{U,j}} V_i^j / S_i^j}{\frac{\gamma_i^{S,NK}}{\gamma_i^{S,NK}+\gamma_i^{U,NK}} V_i^{NK} / S_i^{NK}}, \quad \xi_i^{U,j} = \frac{\frac{\gamma_i^{U,j}}{\gamma_i^{S,j}+\gamma_i^{U,j}} V_i^j / U_i^j}{\frac{\gamma_i^{U,NK}}{\gamma_i^{S,NK}+\gamma_i^{U,NK}} V_i^{NK} / U_i^{NK}} \quad \forall j \in J$$

The first part in the wage wedge expression for skilled labor($\frac{\gamma_i^{S,j}}{\gamma_i^{S,j}+\gamma_i^{U,j}}$) is equal to the fraction of compensation to skilled labor. Thus, by multiplying it by the total value-added in the sector, I can get the total value-added generated by skilled labor, and by dividing it by the total supply of skilled labor in the sector, I can compute the wage rate for skilled labor in the given sector. Lastly, by normalizing wages in each sector with those in the non-capital (NK) sector, I can match the wage wedge parameters with data.

Utility and Production Parameters Since the outer function of utility is given as Cobb-Douglas form as in equation (1.1), the parameter β_i^j can be calculated as the share of each sector goods in final demand. Since each composite goods can be consumed either as final goods or as intermediate

[7] In WIOD SEA, the medium skill labor is defined as workers with equal or lower than secondary education level. So, the grouping in the model is commonly accepted empirical approach.

goods, I calculate the final demand share as $\beta_i^j = \frac{1}{X_i}[X_i^j - \sum_{l\in J}\gamma_i^{j,l}Y_i^l] \ \forall j,l \in J$. Here, X_i is the total expenditure of country i, and X_i^j is the total expenditure for the sector j goods. By substracting intermediate use of sector j goods in the production of sector l, I can sort out the amount of final consumption of sector j goods, and thus calculate the final demand shares.

For the elasticity of substitution parameters (ρ and σ) in the production function, I import widely used parameter values from Krusell et al. (2000). So I set $\rho = 0.67$ and $\sigma = 1.67$. These are the same values used in Parro (2013). Since ρ is the elasticity of the substitution parameter between skilled labor and capital goods, while σ is the parameter between unskilled labor and the composite of capital and skilled labor, the parameter values calibrated above reflect the capital-skill complementarity feature of the model.

1.3.2 Estimated Parameters

Dispersion of Productivity To compute the change in the price of composite goods and trade shares, I need the value of θ^j as in equation (1.13) and (1.14), respectively. Caliendo and Parro (2015) suggests an easily implementable method when the gravity equation takes the form as in equation (2.9). The intuition is that the gravity equation is the expression for the trade flows relative to domestic expenditure. Then, by dividing the trade shares for a given series of countries in one direction to the opposite direction, the domestic expenditure terms will be canceled out, and eventually, trade flows can be expressed as the function of trade costs.

Specifically, consider the three-country i, n, and m. Firstly, the numerator is trade flows from country i to n, n to m, and m to i, while the denominator is in the opposite direction. Then, by equation (2.9), following relation between trade flows and trade costs can be derived:

$$\frac{X_{ni}^j X_{mn}^j X_{im}^j}{X_{in}^j X_{nm}^j X_{mi}^j} = [\frac{\kappa_{ni}^j \kappa_{mn}^j \kappa_{im}^j}{\kappa_{in}^j \kappa_{nm}^j \kappa_{mi}^j}]^{-\theta^j} \tag{1.19}$$

Recall that the overall trade cost is given by $\kappa_{ni}^j = d_{ni}^j(1+\tau_{ni}^j)$. If the iceberg trade cost is symmetric, that is $d_{ni}^j = d_{in}^j$, then the triple log difference of the equation (2.3.2.2) will be changed to:

$$\log[\frac{X^j_{ni}X^j_{mn}X^j_{im}}{X^j_{in}X^j_{nm}X^j_{mi}}] = -\theta^j \log[\frac{(1+\tau^j_{ni})(1+\tau^j_{mn})(1+\tau^j_{im})}{(1+\tau^j_{in})(1+\tau^j_{nm})(1+\tau^j_{mi})}] \tag{1.20}$$

Thus, I can estimate the parameter value θ^j by running the regression of the equation (2.26). The estimation result is reported at Table B.4. This number is similar to the results in other literature using this method, such as Parro (2013) and Caliendo and Parro (2015). In addition, Simonovska and Waugh (2014) suggests the value of θ^j as 0.22, which is quite similar to the result I get. For the non-tradable sector, I use the value $\theta^{NT} = 0.22$.

Trade Costs The estimation of the relative change of trade costs ($\hat{\kappa}$) also relies on the expression of the gravity equation. According to the equation (1.14), the change in trade shares is dependent on the productivity level of exporting countries. Then, by dividing the equation (1.14) with the domestic trade shares, the following relation can be derived:

$$\frac{\hat{\pi}^j_{in}}{\hat{\pi}^j_{nn}} = [\frac{\hat{P}^j_n \hat{\kappa}^j_{in}}{\hat{P}^j_i}]^{-\theta^j}$$

Note that the change of cost of input bundle term ($\hat{c}$) is canceled out because it is dependent on the exporting country, which is the same as country n in the above equation. A similar derivation can be applied to the case when country i is the exporting country and country n is the importing country. Additionally, by multiplying these two results, I get the equation relating the change in trade flows and the change in trade costs.

$$\frac{\hat{X}^j_{ni}\hat{X}^j_{in}}{\hat{X}^j_{ii}\hat{X}^j_{nn}} = [\hat{d}^j_{in}\widehat{(1+\tau^j_{in})}\hat{d}^j_{ni}\widehat{(1+\tau^j_{ni})}]^{-\theta^j}$$

The above equation is congruent with the index introduced in Head and Ries (2001). Lastly, I will assume the symmetry of the iceberg trade cost again. Then, the above equation can be rearranged in terms of iceberg trade cost as follows:

$$\hat{d}^j_{ni} = [\frac{\hat{X}^j_{ni}\hat{X}^j_{in}}{\hat{X}^j_{ii}\hat{X}^j_{nn}}]^{-1/2\theta^j}[\widehat{(1+\tau^j_{in})}\widehat{(1+\tau^j_{ni})}]]^{-1/2} \tag{1.21}$$

Since the trade flows and tariffs can be matched with data as illustrated in the previous section, I get the value of unobservable iceberg trade cost using the equation (1.21). Then, the change in overall trade costs can be constructed as follows:

$$\hat{\kappa}^j_{ni} = \hat{d}^j_{ni}\widehat{(1+\tau^j_{ni})} \tag{1.22}$$

The result of the calculation is summarized in Table (A.2). I can find evidence that, on average, the trade costs in the capital goods sector decrease more than in the non-capital goods sector, which is congruent with the previous literature such as Parro (2013). Recall that in Figure A.1, the export share of capital goods increases over the period. Table A.2 can be one of the reasons to explain the surge in capital goods trade. In line with this finding, the main goal of the quantitative analysis in the paper is to quantify the welfare effects of the asymmetric decrease of trade costs in the capital goods sector and try to link these findings with the specialization dynamics.[8]

1.3.3 Solving the Model

As illustrated in the previous two sections, I can solve the model for the given data and parameter values calibrated to the model. The algorithm used is based on Alvarez and Lucas (2007).

Firstly, I guess the change of wages for each type of labor in the non-capital sector $\hat{w}^{S,NK}$ and $\hat{w}^{U,NK}$. Then, given the parameter values calibrated at the initial year 1995, I calculate the change of cost of input bundles following equation (1.12). Then, the derived change of costs, together with the estimated change of trade costs in the previous section, is plugged into the equation (1.13) to get the change in the price of composite goods.[9] The next step is the gravity equation (1.14). The values of variables obtained in the previous steps are enough to calculate the change in trade shares. Before moving to the equilibrium condition, the intermediate step is recovering the new input shares. With the new values, I can calculate the values of sectoral expenditure by following the equation (1.16).

[8] Parro (2013) refers to the asymmetric trade costs change as the skill-biased reduction in trade costs.

[9] The change of average productivity $\hat{\lambda}^j$ could also be estimated from the trade data, but it requires the price of capital goods. Since the data availability for the price of intermediate goods is limited, I set it to 1, which means the technology level is set to be equal to the initial year level.

Substituting value-added data, new input shares, and sectoral expenditure, I can move on to the labor market equilibrium condition (1.15) and calculate the change of non-capital sector wage for skilled labor ($\hat{w}^{S,NK}$). Note that by definition of the wage wedge parameter($\xi^{S,j}, \xi^{U,j}$), calculating non-capital sector wages is enough to get the wage level in other sectors. The final step is to check whether the trade balance condition (1.17) holds based on the calculated values of variables together with the initial guess of $\hat{w}^{U,NK}$. If not, the initial guess will be updated based on the discrepancy in trade balance conditions, and I iterate the previous steps until I reach the fixed point.

1.4 Quantitative Results

1.4.1 Model Fit

By construction, the model is set to match exactly with the initial year 1995. Based on this, the model solves the relative change of endogenous variables for given parameter values as described in the previous section. Therefore, the model performance could be evaluated by comparing the observed data and model predicted values in 2007.

Figure A.2 represents the scatter plot of the bilateral trade shares, and the line is a 45-degree line. The horizontal axis denotes the observed data in 2007, and the vertical axis is for the model predicted values. Note that the model predicted values of bilateral shares in 2007 are recovered using equation (1.14) and observed data in 1995. If the model fits the data well, points should be close to the 45-degree line. Even though there is some discrepancy between data and model at the extreme values, the figure indicates that the model predicts the data well in the real world. The correlation coefficient between the data and the model values is 0.92. This result implies that the model can reasonably predict when the counterfactual analysis is applied.

1.4.2 Welfare Analysis

Gains from Trade The primary source of shock introduced in solving the model is the change of trade costs as recovered by equation (1.22). In addition, as described in Table A.2, the amount of reduction in trade costs is asymmetrically larger in the capital goods sector. So the main goal of the quantitative analysis in this section is to evaluate the welfare effect of the (asymmetric) reduction in trade costs and to investigate the role of resource reallocation distortions captured by ξ^S, ξ^U.

The utility function in equation (1.1) implies that the preference of the representative agent is homothetic, so the welfare of the agent in the economy can be evaluated by the real income, where the price level is given by equation (1.2). Specifically, the welfare gains of trade can be obtained by the change in real income.

$$\frac{\sum_{j \in J} \alpha^{S,j} \ \hat{\xi}^{S,j} \ \hat{w}^{S,j}}{\prod_{j \in J} (\hat{P}^j)^{\beta^j}} \tag{1.23}$$

The above equation (2.27) is the expression for the change of real wages for skilled labor in a given country. Here, $\alpha^{S,j}$ is the share of the skilled labor in sector j out of the total skilled labor in the country, and it is used as the weight to evaluate the overall change in real wages. Analogously, the change in real wages for unskilled labor can be derived. When the changes in wages for skilled and unskilled labor are added up using the share of skilled labor and unskilled labor out of the total labor as weights, respectively, it will represent the weighted average of changes in wages in the country. It is the measure used in this paper to evaluate the welfare gains of the reduction in trade costs.

Initial Level of Distortion The second step required before exploring the relationship between resource reallocation distortions and welfare gains from trade is to define the overall distortions in a given country. Similarly, as in equation (2.27), I define the weighted average of wage differentials across sectors as follows:

$$\tilde{\xi^S} = \sum_{j \in J} \alpha^{S,j} \xi^{S,j} \tag{1.24}$$

$\tilde{\xi^U}$ can be obtained in the same way. Note that the weighted average is taken at the initial year. Thus, the quantitative work can be interpreted as how the welfare gains from trade in response to the change in trade costs can be differentiated across countries according to the level of labor market distortions in the initial year.

Results Table A.3 summarizes the results of the above welfare evaluation. The first column of Table A.3 is the benchmark case when the gains from trade are calculated under the assumption that there are not any wage differentials across sectors. This measure is the usual one used in previous literature. It can be obtained by suppressing $\hat{\xi}^{S,j} = \hat{\xi}^{U,j} = 1, \forall j \in J$ for all countries in the model. The second column lists the gains from trade when the existence of distortions are reflected by plugging in the values of $\hat{\xi}^{S,j}$, $\hat{\xi}^{U,j}$ as observed in the data.

The main focus of the quantitative work in this paper is comparing the column (1) and the column (2). The result in column (3) indicates that some countries gain more when the distortions are taken into account, while for other countries, the gains from trade are overestimated when we ignore the existence of labor market distortions. One possible explanation is that the relative size of the distortions across countries affects comparative advantages. Thus, ignoring distortions can lead to distinct welfare effects depending on each country's initial condition. A notable feature is that the difference in the gains from trade is negatively correlated with the initial level of distortions in the skilled labor market. The distortions in the skilled labor market have some negative effects to achieve gains from trade liberalization compared to the case when there are no distortions.

Święcki (2017b) also points out that the wage wedges can lead to lower welfare gains in the model with one type of labor. According to Uy et al. (2013), trade liberalization can induce the expansion of comparative advantage sectors to serve the higher demand of the world market. If there are wage differentials across sectors, thus input costs faced by producers are different across sectors, then the determination of comparative advantage is also dependent on the level of wage differentials. Recall that the sectoral wages are equal to the VMPL of each type of labor in the sector. Therefore, the low-productivity sector can be the comparative advantage sector due to the lower labor costs, and the sector will expand over the efficient level in response to the trade liberalization. The same interpretation is possible for the lower gains from trade when the distortions are considered.

Figure A.3 suggests a possible link between the specialization dynamics and the observation of the gains from trade. As shown in section 1.2.7, the relative productivity and input costs will determine the bilateral trade flows, and thus, the model-derived gravity equation contains information on the change in productivity. Specifically, the following derivation is possible:

$$\frac{\hat{\pi}_{ni}^K}{\hat{\pi}_{nn}^K}[\frac{\hat{c}_i^K \hat{\kappa}_{ni}^K}{\hat{c}_n^K}]^{1/\theta^K} = \frac{\hat{\lambda}_i^K}{\hat{\lambda}_n^K} e^{\varepsilon_{ni}^K}$$

Then, by taking logs on both hands side, the following regression equation enables to estimate the change of productivity:

$$\log \frac{\hat{\pi}_{ni}^K}{\hat{\pi}_{nn}^K}[\frac{\hat{c}_i^K \hat{\kappa}_{ni}^K}{\hat{c}_n^K}]^{1/\theta^K} = \log \hat{\lambda}_i^K - \log \hat{\lambda}_n^K + \varepsilon_{ni}^K \tag{1.25}$$

where $\log \hat{\lambda}_i^K$ and $\log \hat{\lambda}_n^K$ can be treated as country fixed effects.

Figure A.3 plots the estimated change in productivity in the capital-intensive sector on the vertical axis and the initial level of distortions in skilled labor on the horizontal axis. The result suggests that the initial distortions in the skilled labor market hinder countries from enhancing productivity in the capital-intensive sector. Figure A.4 corroborates the argument because it shows that skilled labor is more intensively used in the capital-intensive sector. It implies that skilled labor is more crucial inputs for the production of capital goods than unskilled labor. As a result, the distortions in skilled labor market could lead to lower resource reallocation in the capital-intensive sector, which eventually lowers overall welfare gains from trade.

1.5 Conclusion

In this paper, I extends the previous work by Święcki (2017b) into multi-factor model, and provides a theoretical framework to analyze the relations between specialization dynamics and resource reallocation and quantify welfare gains. The quantitative results show that the gains from trade are negatively related to the level of distortions in the skilled labor market in the initial year, and I attribute this result to the lower productivity gain in the capital-intensive sector in countries with higher distortions. This result corroborates the importance of factor reallocation in determining the welfare effects of trade, and it could shed light on the more detailed picture of resource reallocation by including the different skill types of workers.

Despite the findings, there is still much room for improvement in this work. Firstly, and most importantly, only a small number of developing or middle-income countries are included in the analysis. Since those countries are more likely to rely on international trade considering the relatively small size of the economy, and since they suffer more from the labor market frictions due to the lack of skilled labor supply, expanding the data set to include developing and middle-income countries can bring more relevant results. Secondly, the analysis of the relationship between specialization dynamics and resource reallocation now only relies on the empirical relationships. More interesting counterfactual analysis can be conducted based on the model if it could be improved analytically. I hope future research can fill these gaps.

CHAPTER 2

THE WELFARE EFFECTS OF LABOR SWITCHING COSTS IN A TRADE ECONOMY

2.1 Introduction

"Countries can achieve welfare gains from international trade by specializing in their comparative advantages." This is a common message that we impart in many of our undergraduate economics courses. An assumption embedded in traditional trade theories either the Ricardian or Heckscher-Ohlin model - is that workers can freely switch across industries, which enables the resource reallocation needed to realize the welfare gains that flow from trade liberalization. In reality, however, when workers switch sectors, they face a myriad of labor market frictions, including, but not limited to, hiring and firing costs, search-matching costs, and moving costs. These costs matter, since the labor market response to the trade shocks is crucial for determining welfare gains from trade. To this end, this paper provides the estimates of labor market switching costs across 30 countries and investigates the welfare implications of these switching costs in a dynamic general equilibrium trade model. Through a counterfactual trade liberalization with a 20% decrease in trade costs, I find that high switching costs lead to sluggish labor market responses and hinder the achievement of welfare gains from trade.

The recent surge in the trade in intermediate inputs escalates the need to reconsider how we model resource reallocation when evaluating the welfare effects of trade because of the complementarity among production factors. Cheaper intermediate inputs from abroad enhance productivity by directly reducing production costs. In addition, as modeled in the recent trade literature (such as Mutreja, Ravikumar, and Sposi 2018 and Ravikumar, Santacreu, and Sposi 2019), tradable durable goods stimulate capital accumulations because they can be used as investment goods to increase the capital stock. However, due to factor complementarity, these positive effects from foreign intermediate imports are not independently determined from labor market conditions. If labor market frictions are high, workers will remain with the employed sector, and eventually, the labor market rigidity will lower the marginal benefit of imported intermediate inputs.

As an illustrative example, consider the Chinese company Lenovo. When it exports computers to the U.S. market, high-tech imported inputs such as CPUs and display panels are essential for overcoming the technological bottlenecks faced by the company. Moreover, establishing production facilities may be much more difficult without imported machinery. Of course, Lenovo must combine these imported inputs with appropriately trained workers to produce output, and doing so is easier if workers can move across sectors at low cost. The availability of foreign inputs is a common environmental feature across many countries due to worldwide trade liberalization, so the efficiency of the domestic labor market plays a crucial role in determining welfare gains from trade.

To address this research question, I construct a dynamic general equilibrium trade model with sectoral switching costs in the labor market and capital accumulation. The model's static structure is a 30-country, 3-sector extension of the Eaton and Kortum (2002) model as described in Caliendo and Parro (2015). Thus, the model is designed to capture the input-output structure in the global production chain.

The first novel feature of my model is the inclusion of switching costs in the labor market. The sluggish labor market responses generated by switching costs necessitate a dynamic perspective. As introduced in Artuç, Chaudhuri, and McLaren (2010) (ACM 2010, henceforth), in each period of the model, workers optimally sort across sectors to maximize their expected utility. Specifically, workers' utility is composed of two parts - their labor income and idiosyncratic sector-specific preference. However, to switch to another sector, workers have to pay switching costs. This characterization formulates the choice behavior as a dynamic discrete choice problem. Similar to this strand of literature, the idiosyncratic preference is assumed to follow a type-1 extreme value distribution. This assumption simplifies the model-predicted gross labor flows, enabling the estimation of switching costs as explained in section 3.

This paper also extends the standard Eaton and Kortum (2002) model by incorporating capital accumulation. In each country, a representative rentier owns capital and makes the investment decision. This setting allows me to separate the investment from the sector switching behavior of workers, which simplifies the quantitative analysis. One distinguishing feature is that capital-intensive tradable goods (i.e., durable goods) can be used for investment. Thus, trade liberalization enhances productivity through the investment channel as well. In summary, the dynamics in the model are governed by two forces - gross labor flows and capital accumulations.

The quantitative analysis of the paper is conducted in two parts. The first part provides the structural estimates of labor market switching costs across 30 countries. Standard estimation techniques require gross labor flows, typically restricting the analysis to a single country because high-quality gross flow data are usually unavailable for many countries. In contrast, I am able to estimate switching costs for many countries by solving a minimum distance problem between model-simulated and observed labor market dynamics, as suggested by Artuc, Lederman, and Porto (2015) (hearafter, ALP 2015). This estimation method relies only upon readily available aggregate data such as the World Input-Output Database (WIOD), OECD Structural Analysis (STAN), and United Nations Industrial Statistics Organizations Inudstrial Statistics (UNIDO INDSTAT). Despite the inevitable loss of information using aggregate data, the estimation results are compatible with those of previous related studies. On average, workers have to give up approximately 4-years of income to switch to another sector. In addition, compared with the labor market flexibility measure introduced in Cunat and Melitz (2012), workers in a flexible labor market bear lower switching costs. This result confirms the validity of the cross-country comparison of switching cost estimates.

I then embed my estimated switching costs into the dynamic Eaton and Kortum model and solve it. Caliendo, Dvorkin, and Parro (2019) (CDP 2019, henceforth) suggest that under the perfect foresight of workers, the observed allocations can be treated as sufficient statistics for the economy's fundamentals. Thus, I represent the model in a relative time difference form and apply "dynamic hat algebra." Finally, I solve the model with actual data from 1995 to 2006 and compare two counterfactual scenarios from 2006 - (i) a scenario under which the parameters stay constant after 2007, and (ii) a scenario under with there is an unexpected 20% drop in trade costs in 2007. Following the two transition paths, high switching costs slow down labor market responses, hindering workers from moving to high wage-paying sectors. Thus, I confirm that labor market rigidity has a negative effects on welfare gains from trade.

Although this work is preliminary, the theoretical derivation from my model also shows that steady-state income per capita is proportional to total factor productivity (TFP) and capital accumulation, which is similar to neoclassical growth accounting. I hypothesize that labor market switching costs affect the profitability of capital investment through the factor complementarity channel and, eventually, the steady-state income level. I expect that further investigations into the relationship between switching costs and capital accumulation can shed light on the long-run growth effect of trade liberalization.

Labor market responses to international trade has been one of the central questions in the trade literature. For example, Autor, Dorn, and Hanson (2013); Acemoglu, Autor, Dorn, Hanson, and Price (2016); Pierce and Schott (2016) study the employment loss of U.S. manufacturing workers due to the import competition from China. In addition, Ebenstein, Harrison, McMillan, and Phillips (2014) and Liu and Trefler (2019) analyze longitudinal data to track workers' adjustment transition in response to an increase in trade and offshoring.

Some work documents empirical evidence regarding sluggish labor market responses to trade shocks. For example, Menezes-Filho and Muendler (2011) show that Brazilian workers separated from jobs due to import competition tend to take years to find work in a new industry. Dix-Carneiro and Kovak (2017) also use Brazilian data and find that the regional wage differentials caused by trade liberalization remained for more than 20 years. Finally, calibrating a model to U.S. data, Davidson and Matusz (2009) estimated that adjustment costs took away approximately 40% of gains from trade.[1] Tombe (2015); Święcki (2017b) capture labor market frictions with sectoral wage differentials and derive welfare implications through the Eaton and Kortum (2002) model.

The switching cost estimation presented in this paper relates more directly to ACM (2010). There have been recent improvements in the estimation of switching costs using the dynamic

[1] In this work, search frictions constitute is another stream of literature on modelling labor market rigidity. For an extensive exploration, refer to Davidson and Matusz (2009). For recent developments, refer to Coşar (2013); Cacciatore (2014) and Helpman, Itskhoki, Muendler, and Redding (2017).

discrete choice model. Dix-Carneiro (2014) addresses the overestimation problem due to the workers' unobserved heterogeneity. If workers' heterogeneity in human capital is vital in wage determination, the observed wages in another sector can differ from the wages that workers will potentially recieve when they move to that sector. He includes worker characteristics such as age and education in the switching cost estimation to challenge this issue. Traiberman (2019) presents a new perspective on switching costs by focusing on occupation level switching rather than sectoral switching. However, these new estimations require gross labor flow data, which is available only in detailed microdata. As explained earlier, I use the method suggested in ALP (2015) to conduct a comparative cross-country analysis. Additionally, I contribute to this strand of literature by embedding the switching costs in a dynamic general equilibrium model and deriving the welfare implications of the labor market frictions in a trading economy.

The construction of a solution algorithm for the dynamic general equilibrium model is based on a strand of literature that extends the static Eaton and Kortum model to a dynamic setting (Eaton et al., 2016; Mutreja et al., 2018; Ravikumar et al., 2019). In particular, CDP (2019) provide a methodological foundation for applying the dynamic hat algebra in a dynamic model with labor switching costs. As a distinctive contribution of this paper, I include the switching costs for multiple countries while CDP (2019) consider frictions only in the U.S. market. I expect this approach to shed light on the welfare implications of labor market frictions through comparative cross-country analysis.

The rest of the paper proceeds as follows. First, in section 2, I present the model descriptions. Then, I explain the data and estimation process for switching costs. Finally, I demonstrate the model-solving algorithm of the dynamic general equilibrium model.

2.2 Model

In each period, the model specification follows the multi-sector extension of the Eaton and Kortum model as developed in Caliendo and Parro (2015). There are N countries (denoted by $i \in N \equiv \{1, 2, 3, \cdots, N\}$), and 3 sectors. The superscript $J \equiv \{NC, C, NT\}$ represents the non-capital, capital, and non-tradable goods sectors, respectively. The sectors are indexed by j or k. In each sector, a continuum of intermediate varieties is produced by perfectly competitive firms. To be used, these varieties are costlessly combined as composite goods, which can be used either for final consumption or as intermediate goods. Since the sectoral output can also be used as a production factor, the model reflects the input-output structure of the global production chain.

Two additional features make the model dynamic. First, at the end of each period, workers choose an employment sector to maximize their expected utility. However, workers face reallocation costs when switching to another sector. The existence of sectoral labor switching costs captures the extent of the reallocation frictions in the labor market. Overall, optimal choices by workers generate gross flows of labor across sectors. Second, there is a representative rentier in each country who owns and rents the capital stock to firms. Using their capital rental income, rentiers make investment decisions. Thus, the dynamics in the model are governed by two forces, (i) gross labor flows and (ii) capital accumulation.

I first demonstrate the households' utility and their optimal sector choice problem. Then, in the following subsections, I expand the model into a general equilibrium model by adding production and international trade structures.

2.2.1 Households

The number of households employed in sector j at time t is denoted by L_t^j. Each household earns wage income by inelastically supplying a unit of labor.[2] Using their income, they consume sectoral composite goods to maximize their utility.

Consumer Instantaneous utility of the consumers in a country is given by a two-tier utility function where the outer function is a Cobb-Douglas form while the inner component is the constant elasticity of substitution (CES) combination of varieties. Consumers maximize their present value discounted utility as follows:

[2] CDP (2019) provides the extension for the case of inelastic labor supply in their appendix.

$$\max_{C_t^H} \sum_{t=s}^{\infty} \beta^{t-s} \ln(C_t^H) \quad where\ C_t^H = \prod_{j \in J} (C_t^{H,j})^{\alpha^j} \quad and \quad \sum_{j \in J} \alpha^j = 1$$

Here, $C_t^{H,j}$ denotes the final consumption of sector j composite goods by households. The composite goods are the CES combination of sector j varieties. A complete explanation of the varieties and composite goods is provided in the next subsection. Consistently, P_t^j means the price of the sector j composite goods. Then, by the properties of the Cobb-Douglas utility function, the corresponding overall price index in the country can be derived as $P_t = \prod_{j \in J} (P_t^j / \alpha^j)^{\alpha^j}$.

Labor income is the only source of income for households. Therefore, the **budget constraint of consumers in sector** j can be represented as $w_t^j L_t^j \geq \sum_{j \in J} P_t^j C_t^{H,j}$.

Sector Switching Bellman Equation of Labor There is an additional part that composes workers' utility. Each worker enjoys an idiosyncratic preference over the sector they choose for employment. This term can be interpreted as a non-pecuniary benefit provided by the sector.

Specifically, the sequence of each worker's optimization program is defined as follows. First, workers observe the state variables in the economy and the realization of their idiosyncratic preference in sector j denoted by ε_t^j. Then, they work in the currently employed sector and obtain wage income. Lastly, at the end of the period, they have an option to switch to another sector if that sector gives a higher future expected utility. They enjoy their idiosyncratic preference depending on their choices. However, to switch from sector k to j, they incur a cost $\tau^{k,j}$. Thus, the value function for workers employed in sector k at time t can be written as the following Bellman equation:[3]

$$v_t^k = U(C_t^H) + \max_{j \in J} \{\beta E_t[v_{t+1}^j] - \tau^{k,j} + \nu \varepsilon_t^j\} \tag{2.1}$$

where $\tau^{k,k} = 0 \, \forall k \in J$. Here, the expectation is taken over the future realization of idiosyncratic preference shocks, and ν is a scale parameter of preference shocks. Thus, v_t^k can be interpreted as the lifetime value of being employed in sector k at time t.

[3]For notational simplicity, I will omit country index if not necessary.

A standard parametric assumption about the preference shock in the dynamic discrete choice literature is that ε is i.i.d. over time and follows a type-1 extreme value distribution. If we define $V_t \equiv E_t[v_t]$, then by taking expectations on both hands-side, the above equation can be rewritten as follows:

$$V_t^k = U(C_t^H) + E_t \max_{j \in J}\{\beta E_t[V_{t+1}^j] - \tau^{k,j} + \nu \varepsilon_t^j\}$$

Since the expectation is now taken over the current preference shock, V_t^k can be interpreted as the expected lifetime value of a representative worker in sector k. The first term captures the instantaneous benefit from consumption, while the second part shows the value of the options to switch to another sector in the future.[4]

By plugging in the distribution assumption into ε, the value function of workers can be derived as follows:[5]

$$V_t^k = U(C_t^H) + \nu \log[\sum_{j \in J} \exp(\beta E_t V_{t+1}^j - \tau^{k,j})^{1/\nu}] \tag{2.2}$$

In addition, let $\mu_t^{j,k}$ be the fraction of workers who switch from sector j to sector k at the end of t. Then, the distribution assumption implies that the gross flow of labor can be written in the following form:

$$\mu_t^{j,k} = \frac{\exp(\beta E_t V_{t+1}^k - \tau^{j,k})^{1/\nu}}{\sum_{l \in J} \exp(\beta E_t V_{t+1}^l - \tau^{j,l})^{1/\nu}} \tag{2.3}$$

The interpretation of the above expression of the gross labor flow is intuitive. Evaluated at the current period, if the future discounted expected utility in sector k ($= V_{t+1}^k$) is high, then more workers will be likely to move to sector k. However, if the costs incurred by sector switching ($= \tau^{j,k}$) are too high, then the likelihood of switching will decrease.[6]

[4] For the algebraic derivation and interpretation of the option values, refer to Appendix.

[5] The mathematical appendix of ACM (2010) contains the details of the derivation.

[6] $1/\nu$ can be interpreted as migration elasticity with respect to the future wage differentials. In appendix, I discuss the role of $1/\nu$ in detail.

Labor Market Dynamics As explained at the beginning of this subsection, one of the forces that governs the model dynamics is the gross flow of labor. At the end of each t, workers optimally decide the sector they want to be employed in $t+1$. More formally, by the definition of $\mu_t^{j,k}$, the total number of workers who switch from sector j to sector k is $\mu^{j,k} L^j$. Therefore, the following equation represents the labor market dynamics:

$$L_{t+1}^k = \sum_{j \in J} \mu_t^{j,k} L_t^j \tag{2.4}$$

2.2.2 Production

The production side of the model follows the multi-sector Eaton and Kortum (2002) model (Caliendo and Parro, 2015). In each sector, a continuum of firms produces intermediate varieties in a competitive market, and these varieties are combined as composite goods to be used either for final consumptions or as intermediate production factors. The only exception in this paper is the existence of a rentier in each country who owns and rents the capital. The investment decision by the rentier adds another dimension to the dynamics: capital accumulation.

Intermediate Varieties In each sector, there is a mass-1 continuum of firms, and they produce intermediate varieties. The production function of each intermediate variety follows the Cobb-Douglas form:

$$q_t^j(\omega) = z_t^j ((K(\omega)_t^j)^{\xi} (L(\omega)_t^j)^{1-\xi})^{\gamma^j} \prod_{k \in J} (M(\omega)_t^k)^{\gamma^{j,k}} \quad with \sum_{k \in J} \gamma^{j,k} = 1 - \gamma^j$$

Here, $K(\omega)^j$ and $L(\omega)^j$ are the capital stock and labor employed in the production of sector j variety ω, respectively. $M(\omega)^k$ is the composite goods sourced from sector k to produce variety ω in sector j. This formulation follows the round-about input-output structure in the Eaton and Kortum (2002) model. Note that γ^j denotes the share of value-added in sector j production, while $\gamma^{j,k}$ captures the input intensity of sector k goods to produce sector j varieties. Since intermediate inputs are tradable while production factors cannot move across countries, if sector j intensively uses intermediate inputs (that is, $\sum_{k\in J}\gamma^{j,k}$ is high), then cheaper intermediate goods imported from abroad can enhance sector j producers' productivity by reducing their production costs.[7]

The level of productivity in sector j is denoted by z_t^j, which follows a Fréchet distribution with the cumulative distribution function (CDF) $F_i(z) = e^{-\lambda_i^j z^{-\theta j}}$. The average sectoral productivity is denoted by the shifting parameter λ, while θ is the inverse of the dispersion parameter. That is, lower θ implies the dispersion of productivities is higher, thus meaning that there is more room for specialization.

The cost minimization problem of the variety producer implies that the unit cost of input bundle can be written as follows:

$$x_t^j = B^j((r_t)^{\xi}(w_t^j)^{1-\xi})^{\gamma^j}\prod_{k\in J}(P_t^k)^{\gamma^{j,k}} \tag{2.5}$$

where B is a constant, while r, w, and P represent the input costs. Note that rental rates are assumed to be equal across sectors, but sectoral wages do not need be equalized due to frictions in the labor market. A detailed description of the capital market is provided in the latter part of this subsection.

Composite Goods The intermediate varieties should be aggregated into composite goods to be used either for final consumption or as intermediate inputs. The aggregation is costless as follows:

$$Q_t^j = [\int_0^1 q_t^j(\omega)^{1-1/\eta}d\omega]^{\eta/(\eta-1)} = C_t^{H,j} + C_t^{R,j} + \sum_{k\in J}\int_{\Omega} M_t^{k,j}(\omega^k)d\omega^k$$

The first equality is the definition of sectoral composite goods. The second equality captures the input-output structure of the model. That is, sector j composite goods can be consumed either for final goods[8] or as intermediate inputs to produce sector k goods($M^{k,j}$). Note that the price of composite goods can also be derived from the distribution assumption of productivities. However, the

[7] Mutreja et al. (2018) and Ravikumar et al. (2019) find that the decrease of relative price in capital-intensive goods sector leads to higher gains from trade in a dynamic general equilibrium model.

[8] $C^{H,j}$ and $C^{R,j}$ are consumption by households and rentier, respectively

full description requires information about the structure of international trade because intermediate inputs are tradable. Thus, the price of composite goods will be defined once international trade is incorporated into the model.

Rentier There is a representative rentier in each country. This rentier owns capital stock and rents it to domestic firms. With capital income, rentiers also consume like households, but the critical difference is that they also make investment decisions. This setting enables me to separate the sector switching behavior of labor from the investment decision of the rentier.

It is important to note that since tradable capital-intensive sectoral goods are used for investments. Thus, trade liberalization can accelerate capital accumulation by lowering the price of investment. This formulation is similar to recent developments of the dynamic Eaton and Kortum model as in Mutreja et al. (2018); Ravikumar et al. (2019). To focus on the effects of labor market frictions, I assume that there are no frictions in capital reallocation and investment.

Putting all the pieces together, I write the rentiers' optimization problem as follows:

$$max \sum_{t=s} \beta^{t-s} \ln(C_t^R) \qquad subject\ to\ P_t C_t^R + P_t^C I_t \leq r_t K_t$$

where $C_t^R = \prod_{j \in J} (C_t^{R,j})^{\alpha^j}$ is a basket of consumption goods consumed by rentiers and the corresponding price index is the same as in the case of consumers' $P_t = \prod_{j \in J} (P_t^j / \alpha^j)$. Note that the price of investment is the price of capital-intensive goods (P_t^C) as explained above. For notational simplicity, I also define investment rates as follows:

$$\rho_t = \frac{P_t^C I_t}{r_t K_t}$$

Consumption-Investment Euler Equation With this formulation, rentiers face a standard consumption-investment trade-off. By solving their dynamic optimization problem of rentiers', the following consumption-investment Euler equation can be derived:

$$U'(C_t^R) = \beta U'(C_{t+1}^R) \frac{P_t}{P_{t+1}} [\frac{r_{t+1} + P_{t+1}^C (1-\delta)}{P_t^C}] \tag{2.6}$$

Law of Motion of Capital With the above specifications, the capital market dynamics can be written as follows:

$$K_{t+1} = (1-\delta)K_t + I_t \tag{2.7}$$

2.2.3 International Trade

International Trade There are two types of costs associated with international trade. When goods are shipped from country i to country n, firms bear iceberg trade costs of $d_{ni} > 1$. That is, for one unit of goods to be delivered from i to n, $d_{ni} > 1$ goods should be shipped, and it is an unobservable part of the trade costs. The other type of cost is the observable ad-valorem tariff denoted as τ^j_{ni}. The overall trade cost is represented as $\kappa^j_{ni} = d_{ni}(1+\tau^j_{ni})$ and domestic trade is assumed to be costless, that is $\kappa_{ii} = 1$.

Due to trade costs, the price of intermediate varieties shipped from i to n is $x^j_i \kappa^j_{ni}/z^j_i$. Each country n chooses to buy variety ω^j from the lowest-cost source. Therefore, the realized price of intermediate goods in country n is determined as follows:

$$p_n(\omega^j) = \min_i\{\frac{x^j_i \kappa^j_{ni}}{z^j_i}\}.$$

Note that the price of non-tradable goods can also be represented by imposing $d^{NT}_{ni} = \infty$. Thus, $p_n(\omega^{NT}) = \min_i\{p_{ni}(\omega^{NT})\} = p_{nn}(\omega^{NT})$.

Price of Composite Goods Using the properties of the Fréchet distribution, the expression for the price of composite goods under frictional trade can be obtained as follows:

$$P^j_n = \Psi^j(\sum_{i\in I} \lambda^j_i [x^j_i \kappa^j_{ni}]^{-\theta^j})^{-1/\theta^j} \tag{2.8}$$

where $\Psi^j \equiv \Gamma(\frac{\theta^j+1-\eta^j}{\theta^j})^{1/(1-\eta^j)}$ and $\Gamma(\cdot)$ is a gamma function.

Gravity Equation In addition, I denote country n's total expenditure on sector j goods as X_n^j, and country n's total expenditure on sector j goods sourced from country i as X_{ni}^j. Then, the shares of expenditure country n on sector-j goods sourced from country i can be expressed as follows:

$$\pi_{ni}^j = \frac{X_{ni}^j}{X_n^j} = \frac{\lambda_i^j (x_i^j \kappa_{ni}^j)^{-\theta^j}}{\sum_{m \in I} \lambda_m^j [x_m^j \kappa_{nm}^j]^{-\theta^j}} \tag{2.9}$$

This equation is equivalent to the so-called structural gravity equation, and the denominator is a multilateral resistance term. Equation (2.9) shows that the bilateral trade share is the decreasing function of sourcing countries' production costs and bilateral trade costs.

2.2.4 Market Clearing Conditions

In this section, we close the model by deriving market clearing conditions. In the goods market we have trade balance condition. Note that there is no lending and borrowing in this model, so the trade balance condition should be met in each period. The other equilibrium conditions relates to the factor compensation in that aggregate expenditure for each production factor by the variety producers must equal to factor income.

Goods Market Clearing Condition As explained in the subsections above, aggregate composite goods can be used either for final consumption or as intermediate inputs. Notably, however, capital goods can also be used as investments. Thus, the goods market clearing condition for the capital goods sector should be written separately.

$$X_{t,i}^j = \sum_{k \in J} \gamma_i^{k,j} \sum_{n \in N} \pi_{t,ni}^k X_{t,n}^k + \alpha^j \{ \sum_{l \in J} w_{t,i}^l L_{t,i}^l + (r_{t,i} K_{t,i} - P_t^C I_{t,i}) \} \quad for \quad j = \{NC, NT\} \tag{2.10}$$

$$X_{t,i}^j = \sum_{k \in J} \gamma_i^{k,j} \sum_{n \in N} \pi_{t,ni}^k X_{t,n}^k + \alpha^j \{ \sum_{l \in J} w_{t,i}^l L_{t,i}^l + (r_{t,i} K_{t,i} - P_t^C I_{t,i}) \} + P_t^C I_{t,i} \quad for \quad j = \{C\}$$

In the above equations, the first part of the right-hand side represents the intermediate input use of goods. Recall that the production structure in the model fully characterizes the input-output structure, which is captured by $\gamma^{k,j}$ terms. The second part of the right-hand side is the final consumption part. The expenditure share is driven by the Cobb-Douglas utility function parameter. In addition, as explained above, the market clearing condition for the capital goods sector clarifies that capital goods are the source of investments.

Factor Market Clearing Condition For the production factors labor and capital, payments for the factors should be consistent with the value-added share parameters in the production function. Or:

$$L^j_{t,i} = \frac{\gamma^j_i(1-\xi_i)}{w^j_{t,i}} \sum_{n=1}^{N} \pi^j_{t,ni} X^j_{t,n} \tag{2.11}$$

$$K^j_{t,i} = \frac{\gamma^j_i \xi_i}{r_{t,i}} \sum_{n=1}^{N} \pi^j_{t,ni} X^j_{t,n} \tag{2.12}$$

2.2.5 Equilibrium

The dynamic environment in the model necessitates the definition of equilibrium in two ways. First, the optimization conditions and factor allocations should be satisfied in each period, and the sequence of factor endowments should follow labor flows and the capital accumulation conditions.

Cross-Sectional Competitive Equilibrium Note that at a given time period t, the factor endowments L_t and K_t are given. Thus, they can be treated as exogenous variables in a given time. Therefore, the cross-sectional competitive equilibrium can be written as follows:

Definition 1 Given factor endowments $(L_{t,i}, K_{t,i})$ at time t, and the set of parameters $(\gamma^j_i, \gamma^{k,j}_i, \tau_i, \lambda^j_i, \theta^j, \nu, \alpha^j_i, \beta)$ for all $i \in N$ and $j, k \in J$, a *cross-sectional competitive equilibrium* is a vector of wages $w^j_{t,i}$ and rental prices $r^j_{t,i}$ that satisfy the equations (2.5) and (2.8)-(2.12).

Sequential Competitive Equilibrium The sequential equilibrium requires more than the static equilibrium. The two forces that govern the dynamics in the model - labor market dynamics conditions and capital accumulation conditions - should also be met, while at every t, the cross-sectional competitive equilibrium is satisfied. For simplicity (and consistent with the quantitative analysis), the definition of the sequential competitive equilibrium is written with the assumption that the initial period factor endowment $(L_{0,i}, K_{0,i})$ is given.

Definition 2 Given initial factor endowments $(L_{t,i}, K_{t,i})$, and the set of parameters $(\gamma_i^j, \gamma_i^{k,j}, \tau_i, \lambda_{t,i}^j, \theta^j, \nu, \alpha_i^j, \beta)$ for all $i \in N$, $j, k \in J$, and $t \in T$, a *sequential competitive equilibrium* is a sequence of factor prices $(w_{t,i}^j, r_{t,i}^j)$ and allocations (L_t, k_t, μ_t, V_t) that satisfy equations (2.2)-(2.4), (2.6)-(2.7) and the cross-sectional competitive equilibrium at each t.

2.3 Quantitative Analysis

To solve for the sequence of competitive equilibrium, one piece of required information is the labor allocation in each period. Since the labor market dynamics are dependent on the level of switching costs as derived in equations (2.3) and (2.4), the switching cost estimation should be performed before solving the dynamic Eaton and Kortum model. Thus, I divide the quantitative analysis into two parts: (i) estimating the switching costs, and (ii) solving the general equilibrium model.

2.3.1 Step 1. Estimating the Switching Costs

2.3.1.1 Estimation Strategy

Before discussing my estimation strategy, it is worthwhile to derive the ACM (2010) estimation equation with log utility. Under a similar specification but linear utility, they derive an estimation equation by taking the differences between migration flows and the fraction of workers staying in the original sector. The equation below follows the same algebra:

$$(\ln m_t^{j,k} - \ln m_t^{j,j}) = -\frac{(1-\beta)}{\nu}\tau^{j,k} + \frac{\beta}{\nu}(\ln w_{t+1}^{k} - \ln w_{t+1}^{j}) + \beta(\ln m_{t+1}^{j,k} - \ln m_{t+1}^{k,k}) + \xi_{t+1}^{j,k} \quad (2.13)$$

where $\xi_{t+1}^{j,k}$ is a forecast error at $t + 1$ conditional on all information at t. Since the error term may be correlated with the realization of $t + 1$ wages, they use past labor flows and wages as their instrument variables and apply the GMM method to estimate the switching cost term.

Ideally, if the gross labor flows across sectors are observable, I can implement a similar estimation strategy with equation (2.13). With some variations, previous studies such as Artuç and McLaren (2015); Dix-Carneiro (2014), and Traiberman (2019) are also based on similar specifications. However, as I noted in the introduction, high-quality and high-frequency micro-level data containing gross labor flows are not readily available for a large set of countries, especially for developing countries. Thus, the data restriction problem hinders the cross-country comparison analysis of the welfare implications of sectoral labor switching costs.

ALP (2015) suggest a way to estimate switching costs using only aggregate data, and it can be applied to my model as well. The underlying intuition of the method is that even though I cannot directly observe gross flows, I can generate the gross flows through the model and mimic the labor market dynamics using equation (2.4). Then, I can estimate switching costs by constructing a minimum distance problem between he model-generated labor allocation and the observed allocation in data and by treating switching costs as minimizing arguments.

To implement this method, assumptions need to be added.

Assumption 1 To generate the gross flows in equation (2.3), I need the values of $E_t[V_t]$ and τ. Since τ is a minimizing argument, the initial guess value can be substituted in equation (2.3), and the value should be updated to minimize the distance between the model and data. The first assumption used to obtain the value of $E_t[V_t]$ is a **perfect foresight assumption**. That is, the state variable s_t captures all the aggregate shocks in the economy, and each worker takes the sequence of future wages as given when they make sector choice decisions. With this assumption, $E_t[V_{t+1}] = V_{t+1}$, because the only uncertainty in the model is workers' own idiosyncratic preferences.

Assumption 2 Additionally, I assume that **the economy remains constant after** T. This assumption implies that the parameters that characterize the economy remain constant after the end of the period (i.e., 2006 in my data). More formally, it means $V_{T+s} = V_T$, $\forall s > 0$ at the end of the time period T. In this case, solving for the value of V_T is possible using the *contraction mapping theorem*, and then a backward calculation of equation (2.2) obtains the sequence of V_t.

Assumption 3 Lastly, I assume that $\tau^{j,k} = \tau, \forall j \neq k \in J$. Recall that $\tau^{j,j} \equiv 0$. Of course, there is no reason that the switching costs from sector j to sector k are the same as those from sector k to sector j. Rather, it is more desirable to estimate the switching cost matrix to investigate the industry effects on switching behavior. However, the number of parameters increases geometrically, which is a huge challenge considering the data availability. Therefore, for simplicity, I impose a symmetry assumption that switching costs are the same across sectors for a given country, and I leave the refinements of this assumption as a future research agenda as discussed in the following subsection.

Finally, the switching cost τ and migration elasticity ν cannot be separately identified in my algorithm. As derived in equation (2.13), the dispersion parameter of idiosyncratic preference can be interpreted as the inverse of the migration elasticity with respect to the future expected wage differentials. CDP (2019) estimates ν using the same U.S. Current Population Survery (CPS) data as ACM (2010), and the suggests inverse elasticity for annual frequency data is 2.02. Therefore, I calibrate the value and focus on the estimation of switching costs τ. The role of ν is discussed more detail in the appendix.

Algorithm To summarize this subsection, the algorithm I use to estimate the switching cost for a given country can be written as follows. The same algorithm for is applied for all 30-countries.

(1) Guess the value of switching cost τ.

(2) Plug-in to $V_t^k = U(C_t^H) + \nu \log[\sum_{j\in J} exp(\beta E_t V_{t+1}^j - \tau^{k,j})^{1/\nu}]$ to solve for the sequence of V_t.

(3) Generate the gross flows of labor using equation (2.3).

(4) With a given initial allocation of labor, generate the model generated labor allocations using equation (2.4).

(5) Iterate theses steps until the distance between the model and data gets closer enough.

More formally:

$$\hat{\tau} = argmin \sum_{j,t} ((\tilde{L}_{t+1}^j - \tilde{L}_t^j) - (L_{t+1}^j - L_t^j))^2$$

where $\tilde{L}$ is model generated labor allocation, while L is observed data.[9]

2.3.1.2 Data

The data required for the switching cost estimation include the sectoral labor allocations and wages. With the 3-sector classification, the number of observations for each country is too limited to yield significant estimation results. To utilize more observations, in step (i), I expand the manufacturing sector into 8-sectors following International Standard Industrial Classification (ISIC) revision 3 - metals & minerals, chemicals & petroleum products, machinery, food & beverage, wood products, textiles & clothing, miscellaneous equipments, and motor vehicles. The time period used for the estimation is 1995-2006. A detailed description of the data sources is as follows.

Labor Allocations The primary data sources are WIOD Socio-Economic Account (SEA) and OECD STAN. In the WIOD SEA, I used the *EMP* variable for the labor allocations. The variable includes all individuals engaged in sector. The corresponding variable in the OECD STAN is *EMPN*. For countries that are included in both data sources, the estimation results are robust

[9]The expression for the standard error of the estimation is provided in appendix.

regardless of whether the WIOD SEA or OECD STAN is used.

Wages The WIOD SEA and OECD STAN also contain sectoral wage information. WIOD SEA provides sectoral labor compensations (variable *LAB*). Thus, dividing by the number of labor allocations yields labor income. In OECD STAN, I used the *LABR* variable, which reports total labor costs. Again, the results are robust regardless of the data sources.

2.3.1.3 Steady-State Property

Before proceeding to the estimation results, a discussion of the steady-state properties of the labor market dynamics provides useful context. As discussed in McLaren (2017), equations (2.2) and (2.3) imply that the long-run elasticity of sectoral labor supply is positive with respect to the sectoral wage differentials. In the extreme case in which switching costs are zero, the elasticity would be infinite, and sectoral wages should be equalized. Otherwise, the steady-state wage differentials will depend on the steady-state size of the sectors. This property indicates that persistent sectoral wage differentials can be the result of switching costs.

Tombe (2015) and Święcki (2017b) document that a considerable wage wedges are persistent in data. The table below reports the geometric means of sectoral wages across the countries available in the WIOD and OECD STAN.[10]

When wages are normalized to one for the agriculture sector wage, other sectors systematically provide higher labor compensation. Notably, workers employed in capital-intensive and service sectors earn higher wages than workers in other sectors. Thus, if the switching costs are not high enough, more workers would likely reallocate toward the high-paying sectors. However, following the above argument, I can expect high switching cost estimates if I cannot observe the labor flows despite the persistent wage differentials.

[10] Tombe (2015) and Święcki (2017b) embed wage wedges in the Eaton and Kortum model to investigate the welfare effects of labor market rigidity captured by wage wedges.

2.3.1.4 Results

Based on 1995-2006 data, the switching cost estimates are presented in Table B.2. The estimates are normalized to the annual utility level of each country. For example, if the switching cost estimate is 4, the cost is equivalent to the lose of 4-years consumption utility. Note that countries actively participating in the global production network, such as China, India, and Indonesia, have lower switching costs. ALP (2015)examined the relationship between their estimates and well-being indexes such as GDP per capita, employment conditions, and export market developments and found that well-developed institutions lead to more flexible labor markets with lower switching costs.[11] Since my estimates are consistent with those of ALP (2015) in terms of both the order and magnitude, I conclude likewise that the lower mobility costs in China and India enable labor reallocations that generate welfare gains from trade liberalization.[12]

To check the validity of my estimates, I compared observed the labor allocations and model generated allocations. Recall that the estimation algorithm minimizes the distance between them in each period. As shown in Figure B.1, the correlation of the model fits the data quite well.

In addition, I compared my estimates with the labor market flexibility index introduced in Cunat and Melitz (2012). The flexibility measure mainly captures the institutional aspect of the labor market. More concretely, hiring & and firing costs and restrictions to change working hours are the main components affecting the measure. High scores are given to more flexible labor markets. In Table B.3, countries are grouped based on their income level because the switching costs are also dependent on the utility level. In Figure B.2, the overall relationship between the switching costs and flexibility measure is vague. However, for a given income group, there are negative correlations in every income group. Although the labor switching costs and flexibility index focus on different aspects of the labor market, the results provide intuitive explanations. If the labor market is rigid, workers must pay higher costs when switching to another sector.

[11] ALP (2015) include other developing countries in Asia and Latin America. In their analysis, China and India have lower switching costs compared to other developing countries.

[12] Hanson (2012) documents the similar specialization dynamics pattern in China and India. He hypothesizes that the supply of well-educated labor is one of the reasons for the dynamics.

2.3.1.5 Discussion

One possible concern about the approach used above is that all wage differentials are attributed to the switching costs. In this subsection, I discuss this issue and briefly sketch a future research agenda which is intended to complement the current approach accordingly.

Unobserved Heterogeneity One of the potential weakness of the model is that it neglects the unobserved heterogeneity of workers. Instead, it might be more plausible to suppose that each worker has a comparative advantage in a specific sector. In this case, workers cannot expect to receive the observed wage when they switch to another sector because some parts of the compensation would reflect the sector-specific knowledge of workers already employed in the sector. Therefore, attributing the whole sectoral wage differentials to switching costs can lead to an overestimation problem.

To address this issue, Dix-Carneiro (2014) specifies human capital, which is dependent on the worker's gender, age, experience, and sector-specific unobserved heterogeneity. When applied to matched employer-employee data from Brazil, he finds that a considerable amount of switching costs come from the nontransferability of human capital, and common costs are smaller than my estimates or those of ACM (2010). Ashournia (2018) finds that sector-specific human capital matters more in Danish data by applying the same method. Finally, Traiberman (2019) focuses on occupations. In Denmark, occupational switching costs vary across workers and occupations. These results support the concern regarding the overestimation problem of switching costs. Therefore, it is appropriate to interpret the estimates as the upper bound of switching costs.

Of course, the implementation of the estimation with individual fixed effects necessitates micro-level panel data. Therefore, the aforementioned work is constrained to single-country analysis, and this estimation also hinders the inclusion of details of the international trade structure in their counterfactual trade liberalization simulation. Thus, there is a trade-off between the scope of the model and the refinements of the switching cost estimation.

Industry Fixed Effects One possible way to reconcile the two approaches is to decompose switching costs into country and industry effects. Specifically, as sector-specific heterogeneity in human capital affects switching costs, decomposing industry fixed effects can approximate the average effects of sector-specific knowledge. For example, countries A and B may bear different switching costs despite the same labor market institutions because of the industry compositions in the two countries.

A recent literature Dix-Carneiro, Pessoa, Reyes-Heroles, and Traiberman (2021) tries to address this issue by estimating switching costs as a matrix using the U.S CPS data. This method accounts that the transition from industry i to j should be distinguished from the transition from j to i. Due to the dimensionality problem, the authors cannot estimate country specific industry effects, but I expect to better understand labor market rigidity as the future research agenda proceeds.

2.3.2 Step 2. Solving the Sequence of Competitive Equilibrium

2.3.2.1 Dynamic Hat Algebra

Recall that labor flows and capital accumulation govern the dynamics in the model. Therefore, according to Definitions 1 and 2, the equilibrium conditions must be satisfied in each period. Typically, it is not easy to solve a general equilibrium model with a dynamic discrete choice problem and conduct counterfactual analysis. However, as shown in CDP (2019), with the perfect foresight of workers, the observed labor and capital allocations can be treated as sufficient statistics for the economy's fundamentals. Thus, by expressing the model in a relative time difference form, it is possible to reduce the number of parameters required to solve the model. This method is called 'dynamic hat algebra.' [13]

The first step is to re-write the model in a relative time difference form as $\dot{x}_{t+1} \equiv x_{t+1}/x_t$. Then, for the given allocations at time t, it is possible to solve for the "dot" variables and eventually for

[13] A static version of this method is the well-known "exact hat algebra" developed by Dekle et al. (2008).

the $t+1$ equilibrium. More formally:

Proposition 1 Given the equilibrium allocations at t, $\{L_t, K_t, X_t, \rho_t, \pi_t\}$, and given the change of allocations, $\{\dot{L}_{t+1}, \dot{K}_{t+1}, \dot{\rho}_{t+1}\}$, the solution to the competitive equilibrium at $t+1$ for given changes in $(\dot{z}^j_{t+1}, \dot{\kappa}^j_{t+1})$ can be obtained by solving the following non-linear equations:

$$\dot{x}^j_{t+1} = \dot{z}^j_{t+1}\left[(\dot{r}_{t+1})^{\xi}(\dot{w}^j_{t+1})^{1-\xi}\right]^{\gamma^j}\prod_{k\in J}(\dot{P}^k_{t+1})^{\gamma^{k,j}} \tag{2.14}$$

$$\dot{P}^j_{t+1} = \left[\sum_{j\in J}\pi^j_{t,ni}(\dot{x}^j_{t+1,i}\dot{\kappa}^j_{t+1,ni})^{\theta^j}\right]^{-1/\theta^j} \tag{2.15}$$

$$\pi^j_{t+1,ni} = \pi^j_{t,ni}\left(\frac{\dot{x}^j_{t+1,i}\dot{\kappa}^j_{t+1,ni}}{\dot{P}^j_{t+1}}\right)^{-\theta^j} \tag{2.16}$$

$$\dot{w}^l_{t+1,i}\dot{L}^l_{t+1,i}w^l_{t,i}L^l_{t,i} = \gamma^l_i(1-\xi_i)\sum_{n\in N}\pi^l_{t+1,ni}X^l_{t+1,n} \tag{2.17}$$

$$\dot{r}^l_{t+1,i}\dot{K}^l_{t+1,i}r^l_{t,i}K^l_{t,i} = \gamma^l_i\xi_i\sum_{n\in N}\pi^l_{t+1,ni}X^l_{t+1,n} \tag{2.18}$$

$$\begin{aligned} X^j_{t+1,i} &= \sum_{k\in J}\gamma^{k,j}_i\sum_{n\in N}\pi^k_{t+1,ni}X^k_{t+1,n} \\ &+ \alpha^j\{\sum_{l\in J}\dot{w}^l_{t+1,i}\dot{L}^l_{t+1,i}w^l_{t,i}L^l_{t,i} + (\dot{r}_{t+1,i}\dot{K}_{t+1,i}r_{t,i}K_{t,i} - \dot{\rho}_{t+1,i}\rho_{t,i}\dot{r}_{t+1,i}\dot{K}_{t+1,i}r_{t,i}K_{t,i})\} \\ &for\ \ j\in\{NC, NT\} \end{aligned} \tag{2.19}$$

$$\begin{aligned} X^j_{t+1,i} &= \sum_{k\in J}\gamma^{k,j}_i\sum_{n\in N}\pi^k_{t+1,ni}X^k_{t+1,n} \\ &+ \alpha^j\{\sum_{l\in J}\dot{w}^l_{t+1,i}\dot{L}^l_{t+1,i}w^l_{t,i}L^l_{t,i} + (\dot{r}_{t+1,i}\dot{K}_{t+1,i}r_{t,i}K_{t,i} - \dot{\rho}_{t+1,i}\rho_{t,i}\dot{r}_{t+1,i}\dot{K}_{t+1,i}r_{t,i}K_{t,i})\} \\ &+ \dot{\rho}_{t+1,i}\rho_{t,i}\dot{r}_{t+1,i}\dot{K}_{t+1,i}r_{t,i}K_{t,i}\ \ for\ \ j\in\{C\} \end{aligned}$$

Note that I need to solve for $(\dot{w}^j_{t+1}, \dot{r}^j_{t+1}, \dot{x}^j_{t+1} \dot{P}^j_{t+1}, \pi^j_{t+1}, X^j_{t+1})$ with the 6-equations above. One important implication of Proposition 1 is that without knowing the levels of the time-varying parameters, one can solve for the $t+1$ allocations through the $t+1$ dot variables and initial allocations. The fact that one can treat the change in productivity and trade costs as exogenous significantly simplifies conducting counterfactual analysis. For example, if I assume a counterfactual scenario with the parameters staying constant after T, I can simply include $\dot{z}^j_{T+1} = 1$ and $\dot{\kappa}^j_{T+1} = 1$.

Proposition 1 is based on the assumption that the change of factor allocations $\{\dot{L}_{t+1}, \dot{K}_{t+1}, \dot{\rho}_{t+1}\}$ is given. However, since the allocations are also equilibrium outcomes, it is more appropriate to derive the factor allocation dynamics endogenously. The following proposition clarifies how the factor dynamics work:

Proposition 2 Given the initial allocation of the economy, $\{L_t, K_t, I_t, X_t, \rho_t, \mu_{t-1}, \pi_t\}$, the solution to the sequence of competitive equilibrium in time differences can be obtained by solving the following non-linear equations:

$$\mu^{j,k}_t = \frac{\mu^{j,k}_{t-1}(\dot{u}^k_{t+1})^{\beta/\nu}}{\sum_{l\in J} \mu^{j,l}_{t-1}(\dot{u}^l_{t+1})^{\beta/\nu}} \tag{2.20}$$

$$\dot{u}^j_{t+1} = \dot{\omega}^j_{t+1}(\mu^{j,k}_t (\dot{u}^k_{t+2})^{\beta/\nu})^\nu \tag{2.21}$$

$$L^j_{t+1} = \sum_{k\in J} \mu^{k,j}_t L^j_t \tag{2.22}$$

$$\dot{\rho}_{t+1} = \frac{\dot{P}^C_{t+1}}{\dot{r}_{t+1}} \frac{\dot{I}_{t+1}}{\dot{K}_{t+1}} \tag{2.23}$$

$$\frac{1-\rho_{t+1}}{1-\rho_t}\dot{r}_{t+1}\dot{K}_{t+1} = \beta\left[\dot{r}_{t+1}\left(\frac{\dot{K}_{t+1-(1-\delta)}}{\rho_t}\right) + \dot{P}^C_{t+1}(1-\delta)\right] \tag{2.24}$$

$$K_{t+1} = (1-\delta)K_t + I_t \tag{2.25}$$

where $u_t^j \equiv \exp(V_t^j)$, $\omega_t^j \equiv \frac{w_t^j}{P_t}$, and $(\dot{\omega}_t^j, \dot{r}_t)$ is the solution to the competitive equilibrium at each t.

Proposition 2 shows that for the given initial conditions, one can derive the sequence of labor and capital allocations through the factor dynamics conditions, respectively. Thus, by combining the results i Propositions 1 and 2, I can repeatedly solve for the sequence of competitive equilibrium with the generated factor allocations in hand. The algorithm used is described below.

Algorithm The algorithm to solve the model is composed of 3 steps. The first step involves guessing the sequence of investment expenditure in order to generate the sequence of the capital stock. In the second step I guess the sectoral value functions of workers. With this conjecture in hand, I can calculate the gross labor flows and generate the labor market dynamics. Finally, for the given sequence of factor allocations, the model is solved for each t following the results derived in Proposition 1. Detail are provided in appendix.

2.3.2.2 Take the Model to the Data

The data required to solve the model are trade flows $\pi_{t,ni}^j$, the value-added of labor $(w_t^j L_t^j)$ and capital $(r_t K_t)$, and gross labor flows $\mu_t^{j,k}$. [14] I set the year 1995 as the initial period and solve for the model from 1995 to 2006.

Sector Classification As illustrated in the model section, I aggregate the data into 3-sectors based on ISIC version 3. Similar to Mutreja et al. (2018); Ravikumar et al. (2019), the non-capital intensive sector corresponds to ISIC code 01-28; the capital-intensive sector matches 29-35; non-tradable sector includes agriculture and service industries.

[14] Since I cannot observe gross labor flows as data, I bring the model generated flows from Step 1 switching cost estimation.

Trade Flows Recall that the bilateral trade share is defined as imports divided by domestic expenditure, as in equation (2.9). The primary data source for constructing trade data is the WIOD. One of the benefits of using the WIOD is that it contains trade flows and production information. First, I calculate the sectoral domestic expenditure (X^j_{nn}) as the difference between the value of the gross output and the value of the total exports of the sector. Then, the total expenditure of the sector (X^j_n) can be computed as the sum of the domestic expenditure and total import of sector j goods.

Input Cost Shares and Value-Added Since the WIOD has data on input-output linkages, I can calibrate the input share parameters ($\gamma^{j,k}_n$) by taking the ratio between intermediate consumption and gross output. The value-added ratio (γ^j_n) can be similarly derived. In addition, by using the labor and capital compensation variable, I can obtain the share of capital expenditure among value-added (ξ_n). Since the production parameters are assumed to be time-invariant for simplicity, I take the median of each variable across years.

Dispersion of Productivity One of the key parameters in quantitative trade models is the dispersion of productivity θ^j, that is, the inverse of trade elasticity. I followed the method suggested by Caliendo and Parro (2015) to estimate θ^j. The intuition is that the gravity equation is the expression for trade flows relative to domestic expenditure. Thus, by dividing the trade shares for a given series of countries in one direction to the opposite direction, the domestic expenditure terms cancel out, and eventually, trade flows can be expressed as a function of trade costs.

Specifically, consider three countries i, n, and m, and the chain of trade flows among them. By equation (2.9), the following relationship between trade flows and trade costs holds:

$$\frac{X^j_{ni}X^j_{mn}X^j_{im}}{X^j_{in}X^j_{nm}X^j_{mi}} = [\frac{\kappa^j_{ni}\kappa^j_{mn}\kappa^j_{im}}{\kappa^j_{in}\kappa^j_{nm}\kappa^j_{mi}}]^{-\theta^j}$$

Recall that the overall trade cost is given by $\kappa^j_{ni} = d^j_{ni}(1+\tau^j_{ni})$. If the iceberg trade cost is symmetric, that is $d^j_{ni} = d^j_{in}$, then the triple log difference of the above equation leads to the following:

$$\log[\frac{X_{ni}^j X_{mn}^j X_{im}^j}{X_{in}^j X_{nm}^j X_{mi}^j}] = -\theta^j \log[\frac{(1+\tau_{ni}^j)(1+\tau_{mn}^j)(1+\tau_{im}^j)}{(1+\tau_{in}^j)(1+\tau_{nm}^j)(1+\tau_{mi}^j)}] \tag{2.26}$$

Thus, the OLS regression of equation (2.26) estimates the dispersion of productivity parameters, and the results are reported in Table B.4. The estimates are similar to the results in other literature using the same method.[15]

Model Fit I conclude this subsection with the model fit results. Figures B.3 and B.4 plot observed bilateral trade shares (on the horizontal axis) and model generated trade shares (on the vertical axis) in 1996 and 2006, respectively. The high correlations between the model and data suggest that the model fits the data quite well. In particular, one concern is that the distance between the model and data becomes far as the analysis period proceeds because I need to include the model solved outcome variables at $t + 1$ as the initial values to solve for $t + 2$ values. However, despite this concern, the correlation between the model and data is still high in 2006, confirming the validity of quantitative analysis.

2.3.2.3 Counterfactual Analysis

To evaluate the welfare effects of switching costs, I conduct counterfactual analysis in two scenarios - (i) a scenario under which the parameters stay constant after 2007, and (ii) a scenario under which there is an unexpected 20% drop of trade costs at 2007. As explained in the subsection above, after applying the dynamic hat algebra, the model-solving algorithm requires only the change in parameters. This property simplifies the counterfactual analysis.

Figure B.5 shows the half-life to reach the new steady-state for each country. As we would expect, higher switching costs lead to sluggish labor market responses. The rigidity delays the economy from achieving the benefits of trade liberalization. We next turn to the welfare implica-

[15] For the non-tradable sector, I set the value of θ^j as 0.22, as suggested by Simonovska and Waugh (2014).

tions.

Gains from Trade In static quantitative trade models, welfare gains from trade are expressed as the difference of real consumption in the two regimes Arkolakis et al. (2012) derived the well-known ACR formula in this comparison.[16] However, one distinctive advantage of dynamic models is that there is a transition path that can taken into account. For example, even when a country reaches the same level of steady-states in different regimes, the adjustment periods can drive a wedge between the overall welfare gains. Specifically, as similar to ACM (2010), I define the welfare measure as the compensating variation in consumption in sector j at time t (η^j) as follows:[17]

$$V_t'^j = V_t^j + \sum_{s=t}^{\infty} \beta^{s-t} \log(\eta^j)$$

where V_t^j and $V_t'^j$ is the value of being employed in sector j at time t under a counterfactual scenario (i) and (ii), respectively.

In addition, the parametric assumptions in the model imply that the present discounted value of compensating variation is:

$$\log(\eta^j) = \sum_{s=t+1}^{\infty} \beta^{s-t} \log\left[\frac{\hat{C}_s^j}{(\hat{\mu}_s^{j,j})^{\nu}}\right] \quad where \;\; \hat{C} \equiv \dot{C}'/\dot{C} \tag{2.27}$$

In equation (2.27), the welfare gains from trade can be divided into three sources. First, the benefit of lower price final consumption goods is directly captured by the change of consumption. Additionally, productivity gains from cheaper intermediate goods affect the consumption level because the model reflects the input-output structure of the global production chain. Finally, the $\hat{\mu}^{j,j}$ term on the right-hand side captures the labor mobility. A higher $\hat{\mu}^{j,j}$ means less reallocation in the labor market and, in turn, workers have to delay enjoying the benefit of trade liberalization even when the other sector offers high expected utilities. Recall that the algebraic meaning of

[16]Costinot and Rodríguez-Clare (2014) extensively review the derivation of welfare measure in quantitative trade model.

[17]I attached the details of the derivation in appendix.

$-\nu \log \mu^{j,j}$ is the value of option to switch to the other sector as derived in appendix. Thus, the third channel represents how the change of option values affect the welfare of workers.

The negative relationship between the level of switching costs and the countries' overall welfare gains from trade are clear from Figure B.6. In addition, Figure B.7 plots the fraction of option values in each country's welfare gains from trade. On average, the optional value takes approximately 4% among the welfare effects, and the share is negatively correlated with the level of switching costs. A policy implication driven from this analysis is that facilitating workers' reallocation and reducing the adjustment period is beneficial for achieving welfare gains following the transition path.

2.3.2.4 Future Research Agenda

Although this work is preliminary, the theoretical derivation from my model shows that steady-state income per capita is proportional to total factor productivity and capital accumulation as follows:[18]

$$y_{it} \propto \underbrace{(\frac{T_{NT,i}}{B_{NT,i}})(\frac{(\frac{T_{NT,i}}{\pi_{ii}})^{1/\theta}}{B_{NC,i}})^{(1-\gamma_{NT,i})/\gamma_{NC,i}}}_{measured\ TFP}(\tilde{k}_{it})^{\xi} \tag{2.28}$$

where B are constants, y_{it} is income-per-capita, and $\tilde{k}_{it}$ is capital-labor ratio. This expression is similar to the results in neoclassical growth accounting. That is, the steady-state income level depends on the TFP and factor accumulations. Recall that, as discussed in the subsection above, factor allocations can be associated with structural change and dynamics of specialization patterns (Hanson 2012; Święcki 2017a). Similarly, I hypothesize that the positive effects of international trade are closely related to labor market switching costs due to the factor complementarity. For example, if workers remain in the employed sector because of high switching costs, then the profitability of capital investment will be mitigated, and eventually, the steady-state income level will be affected. I expect that further investigations into the labor market rigidity and capital accumulation can add a new perspective on the long-run growth effect of international trade.

[18] Note that, for this derivation, I ignored sectoral wage differentials due to algebraic simplicity.

2.4 Conclusion

Labor market adjustment is crucial for determining the welfare gains from trade because it enables required resource reallocation in response to trade liberalization. The recent surge in the trade in intermediate inputs reinforces the need to model resource reallocation when evaluating the welfare effects of trade due to the complementarity among production factors. To this end, I build a dynamic general equilibrium model with sectoral switching costs in the labor market and capital accumulation.

In each period of the model, workers optimally choose the employment sector to maximize their expected utility. However, to switch to another sector, they have to pay switching costs. I formulate the worker's behavior as a dynamic discrete choice problem and estimate switching costs by solving a minimum distance problem between the model-simulated and observed labor dynamics. Using readily available data such as WIOD and OECD STAN, I provide estimates of switching costs across 30 countries. The results indicate that workers have to give up approximately 4-years of income to switch to another sector, and the costs get lower when the country has a flexible labor market.

In addition, I embed my estimates into a dynamic Eaton and Kortum model to evaluate the welfare implications of switching costs through a comparative cross-country analysis. In a counterfactual trade liberalization with a 20% decrease in trade costs, I find that high switching costs lower welfare gains from trade by impeding workers from moving to high wage-paying sectors.

The results suggest an important policy implication that reducing labor market frictions can enhance the ability to achieve welfare gains from trade. In addition, my framework can be extended to explore the relationship between labor market frictions and structural change. I expect that this extension can contribute to the literature in the welfare evaluation of international trade.

APPENDICES

APPENDIX A

SUPPLEMENTS OF CHAPTER 1

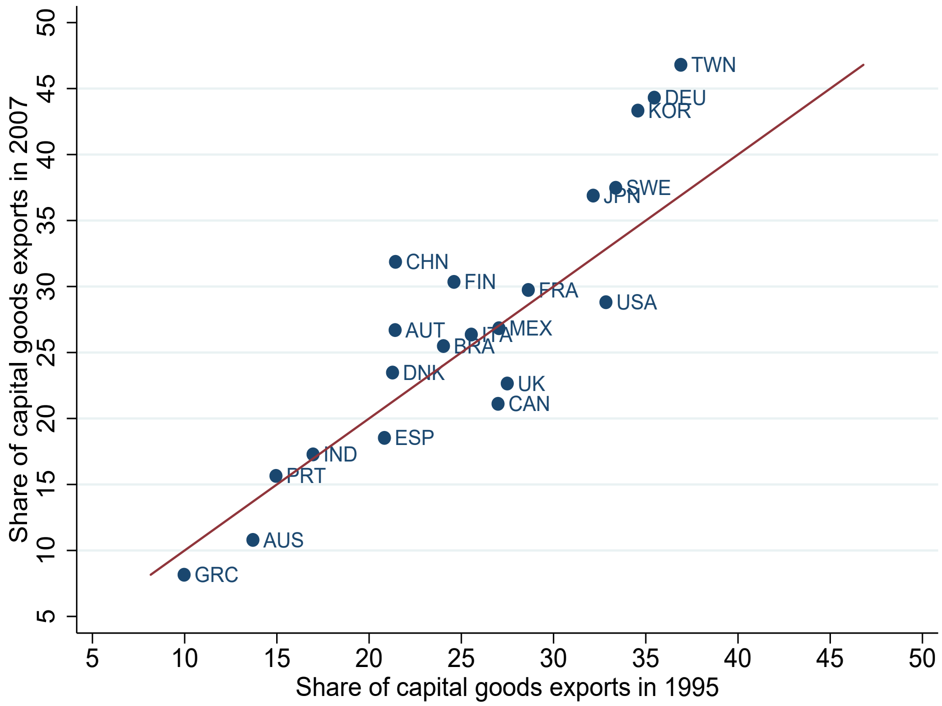

Figure A.1: The Rise of Capital Goods Export

Notes: This figure plots the share of capital-intensive goods export out of total exports. Horizontal axis is values in 1995, and vertical axis is values in 2007. If the plot is above the 45-degree line, it means that the country's capital goods export share increases over the period.

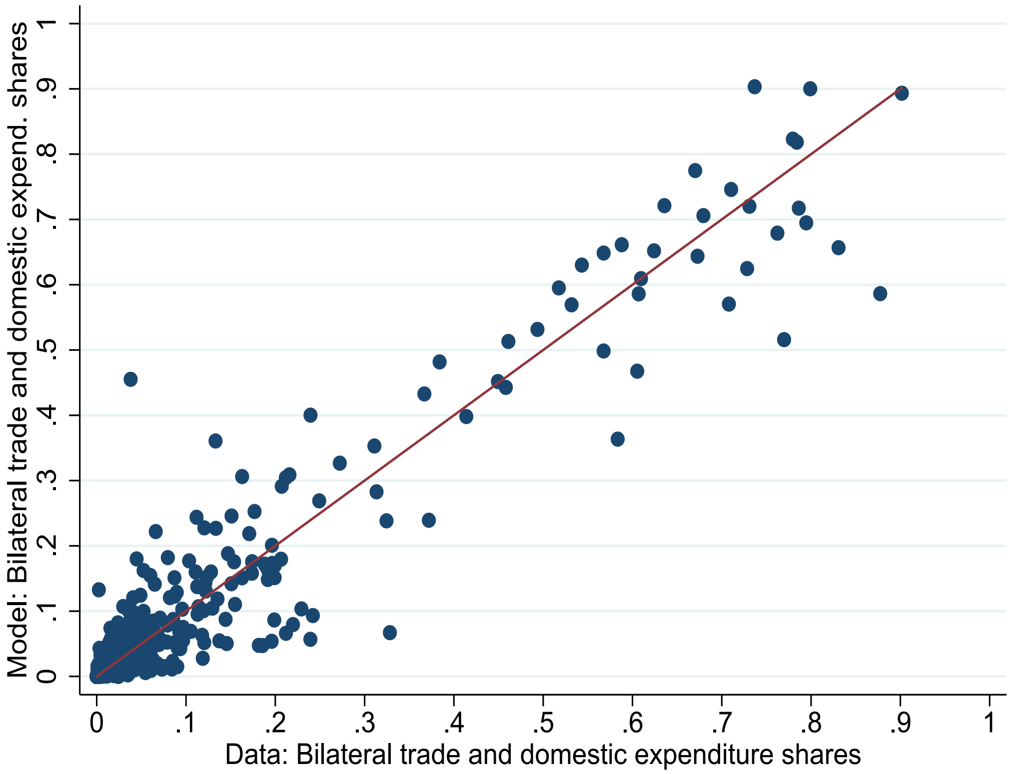

Figure A.2: The Scatter Plot of Bilateral Trade Shares at 2007 (Data vs Model)

Notes: This figure compares model-driven and data bilateral trade flow shares at 2007. Overall correlation is 95%. This means that the model works well to mimic the real economy.

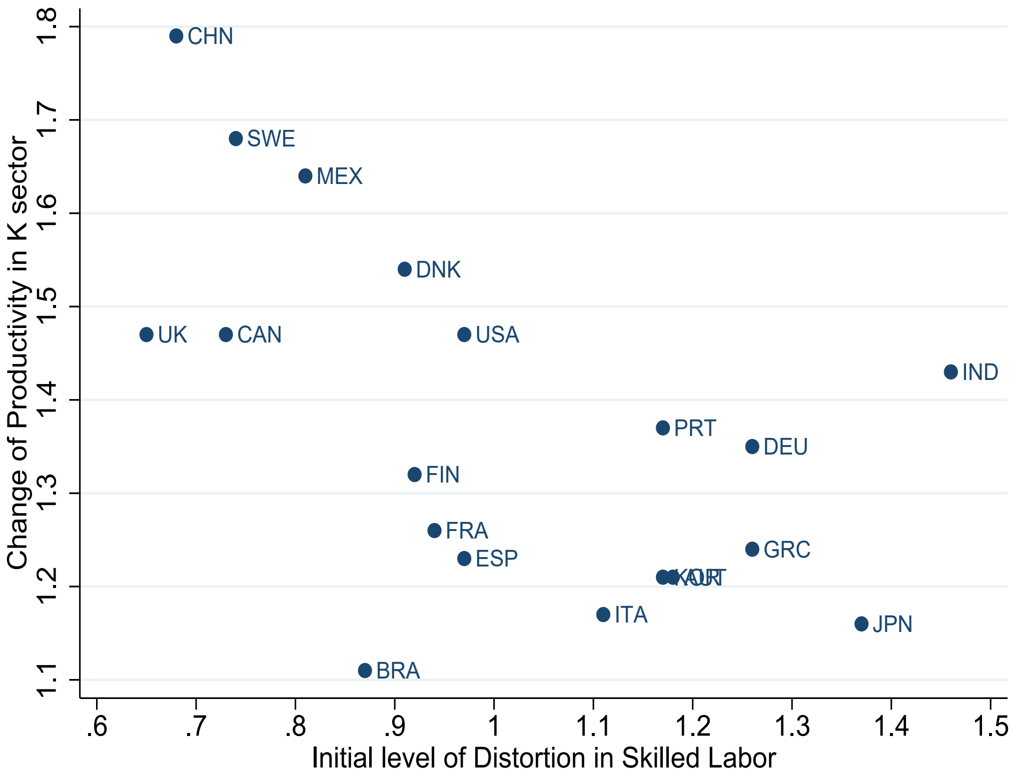

Figure A.3: The Change of (revealed) Productivity in Capital-Intensive Sector 1995 to 2007

Notes: The change of (revealed) productivity in capital-intensive sector between 1995 and 2007 is calculated using equation (1.25).

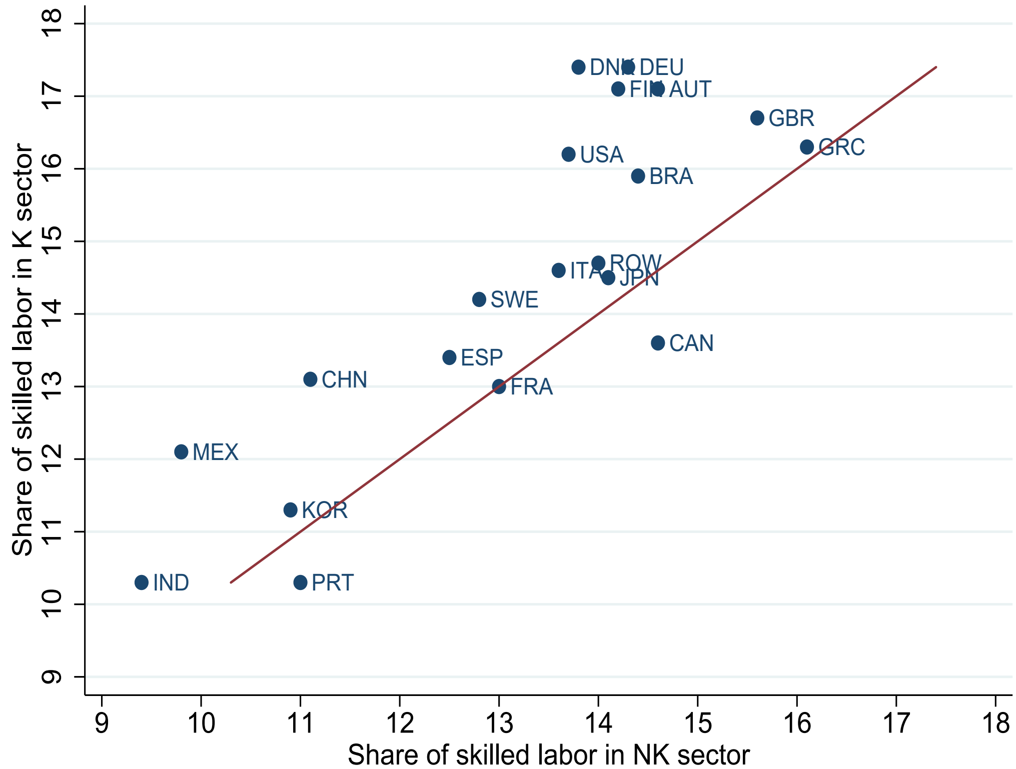

Figure A.4: The Cost Share of Skilled Labor Comparison

Notes: The cost sharer of skilled labor in total production costs are calculated from WIOD.

Table A.1: Estimation of the Productivity Dispersion

sector	θ^j	s.e.	95% C.I.
capital goods	0.21	0.03	(0.16, 0.27)
non-capital goods	0.18	0.02	(0.14, 0.22)

Notes: The robust standard errors are reported and the confidence interval is calculated using the standard errors.

Table A.2: Estimation of the Change of Trade Costs

sector	Obs	Mean	Std.Dev	Min	Max
Capital goods	380	0.79	0.15	0.24	1.09
Non-capital goods	380	0.88	0.11	0.41	1.20

Notes: The change of trade costs between 1995 and 2007 are calculated using equation (1.22). The trade costs decrease more in capital-intensive sector, which can be interpreted as the enhanced effect of global production chain.

Table A.3: Estimation of Change of Trade Costs

Country	(1) *GFT* *No distortion*	(2) *GFT* *With distortion*	(3) *Diff.* (2) - (1)	(4) $\tilde{\xi}^S$	(5) $\tilde{\xi}^U$
Austria	5.84	6.56	0.72	1.18	1.27
Brazil	1.09	3.57	2.48	0.87	1.33
Canada	3.12	3.02	-0.10	0.73	0.95
China	11.10	14.53	3.43	0.68	1.15
Germany	4.02	5.77	1.75	1.26	1.20
Denmark	3.23	3.81	0.58	0.91	1.07
Spain	3.76	3.90	0.13	0.97	1.08
Finland	2.77	4.22	1.45	0.92	1.08
France	2.08	4.15	2.07	0.97	1.07
United Kingdom	2.62	3.94	1.33	0.65	0.78
Greece	1.42	0.86	-0.55	1.26	1.14
India	5.03	3.55	-1.48	1.46	1.39
Italy	3.24	2.95	-0.29	1.11	1.14
Japan	0.56	0.69	0.13	1.37	1.15
Korea	3.68	4.01	0.33	1.17	1.02
Mexico	6.30	10.02	3.72	0.81	1.38
Portugal	5.95	6.17	0.23	1.17	1.34
Rest-of-the-World	2.80	5.14	2.34	1.13	1.18
Sweden	4.73	5.54	0.81	0.74	0.98
United States	0.96	1.22	0.27	0.97	1.04
correlation w/ (3)				-0.53	0.13

Notes: Column (1) is the gains from trade without distortion case, and column (2) is the gains from trade with distortions. Column (3) calculates the difference between columns (1) and (2). Column (4) shows the correlation between the initial level of distortions in skilled labor and column (3). The negative correlation means the distortions in skilled labor have negative effect on the gains from trade. Column (5) shows the correlation between the initial level of distortions in unskilled labor and column (4), which has lower correlation.

APPENDIX B

SUPPLEMENTS OF CHAPTER 2

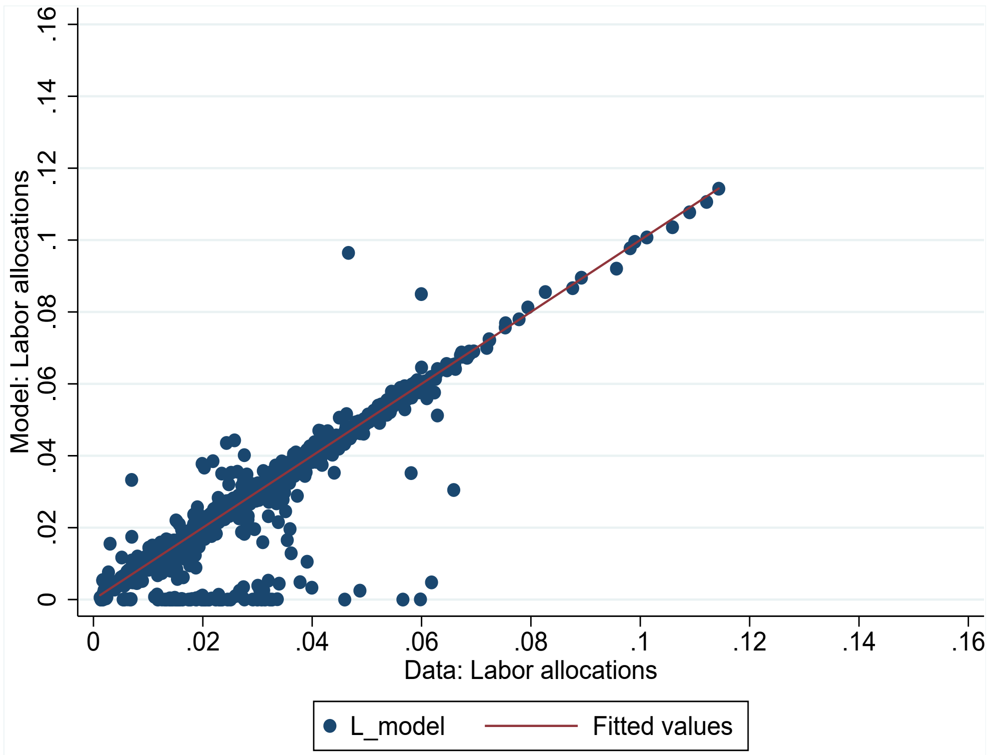

Figure B.1: Comparison between Model and Data Labor Allocations

Notes: Overall correlation of the model and data is 0.96.

Figure B.2: Switching Costs and Labor Market Flexibility Index

Notes: Cunat and Melitz (2012) & Author's calculation.

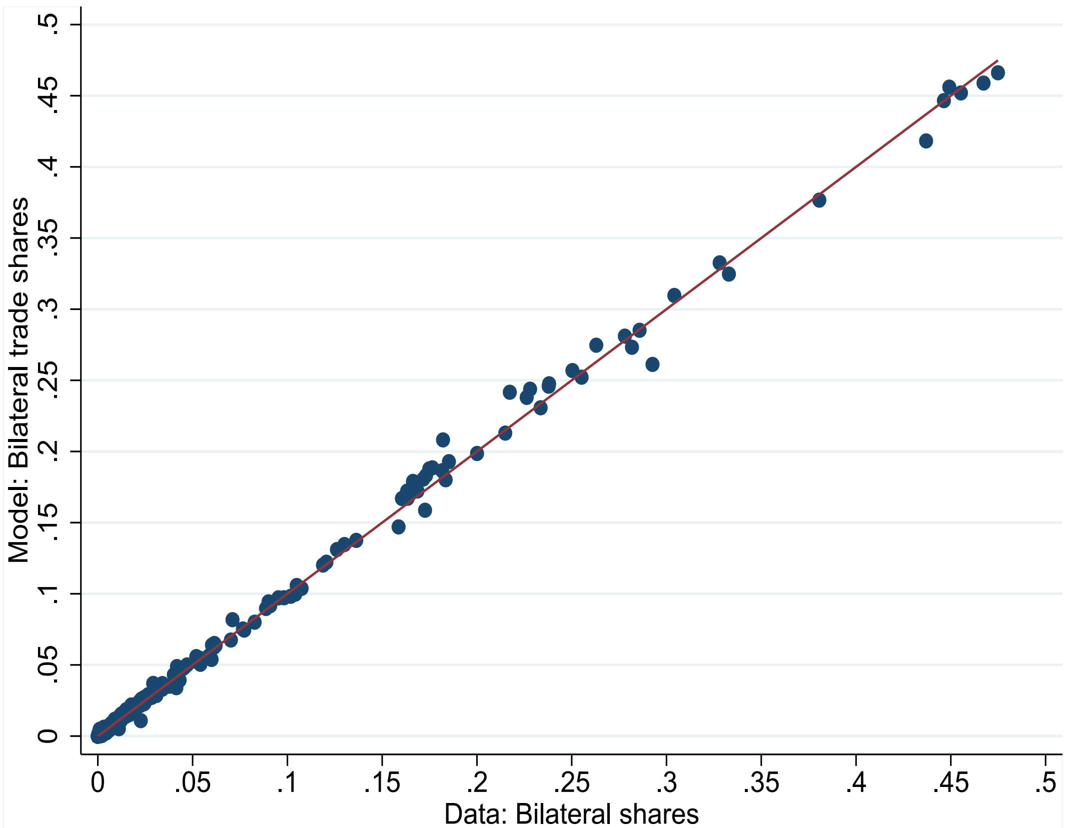

Figure B.3: Data vs Model Bilateral Trade Shares in 1996

Notes: The correlation between the model and data is 0.99.

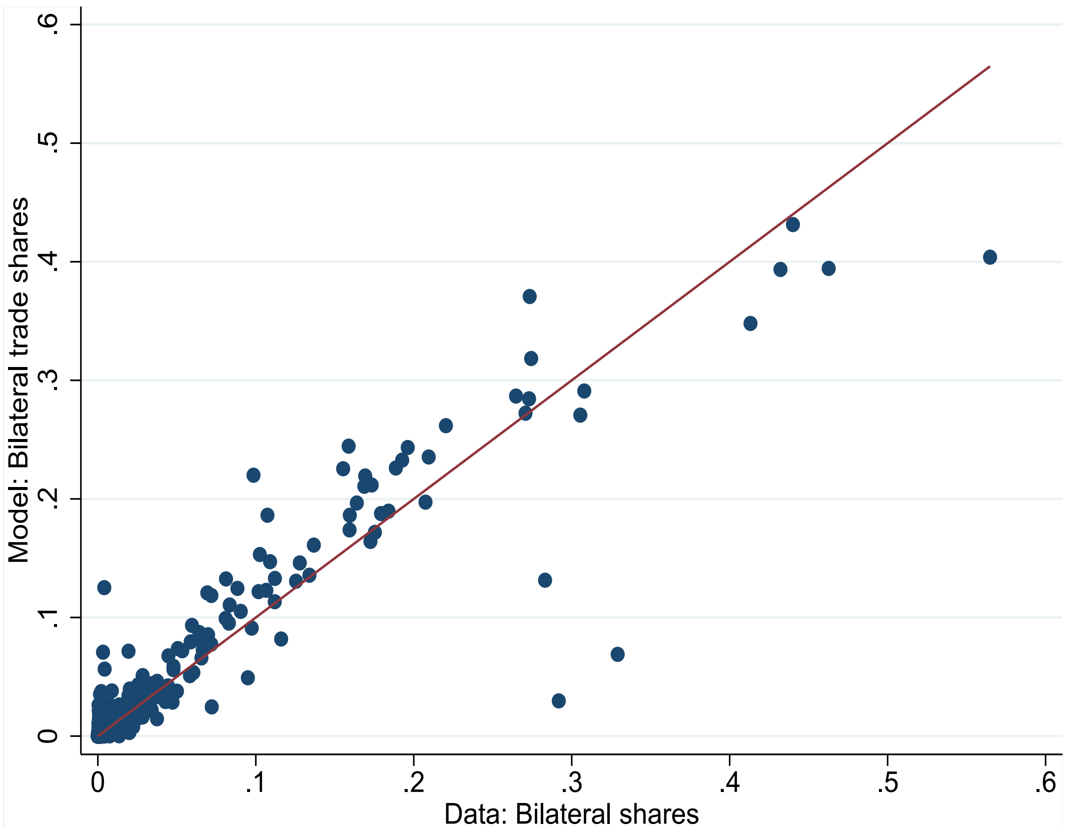

Figure B.4: Data vs Model Bilateral Trade Shares in 2006

Notes: The correlation between the model and data is 0.94.

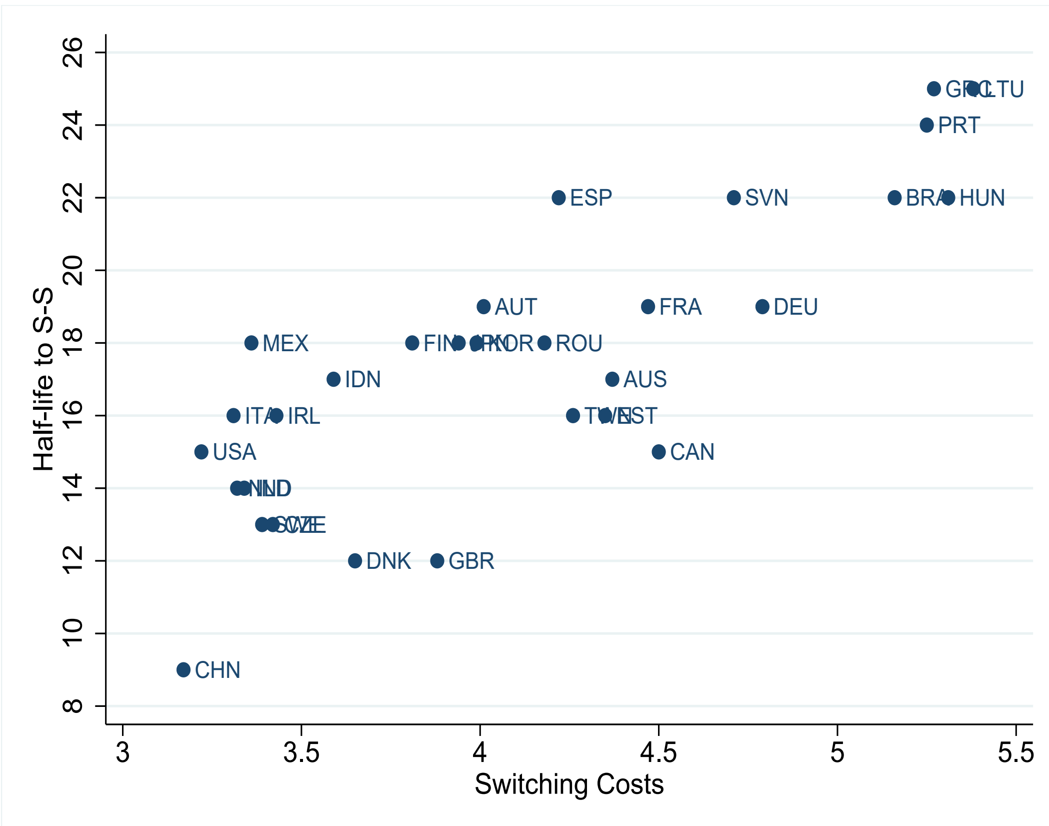

Figure B.5: Half-life to Reach Steady-state

Notes: The number of years each country takes to reach to the midpoint between initial endowment and steady state.

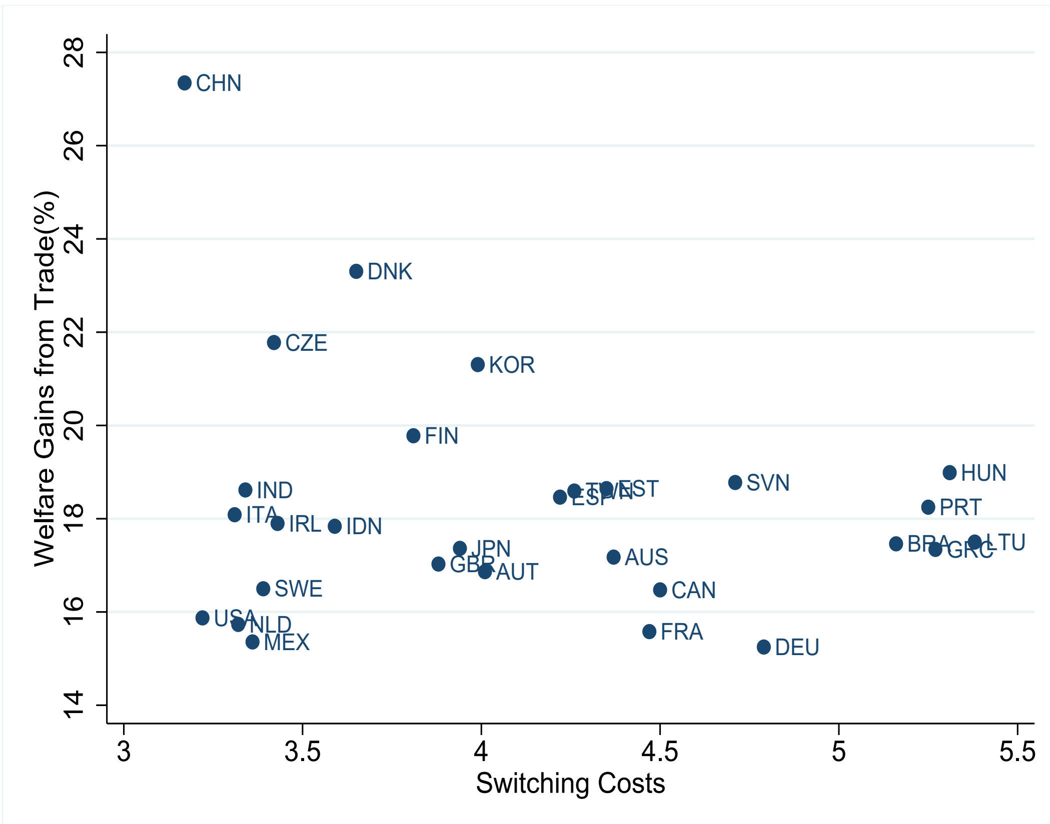

Figure B.6: Welfare Gains from Trade

Notes: Welfare gains from trade calculated with equation (2.27).

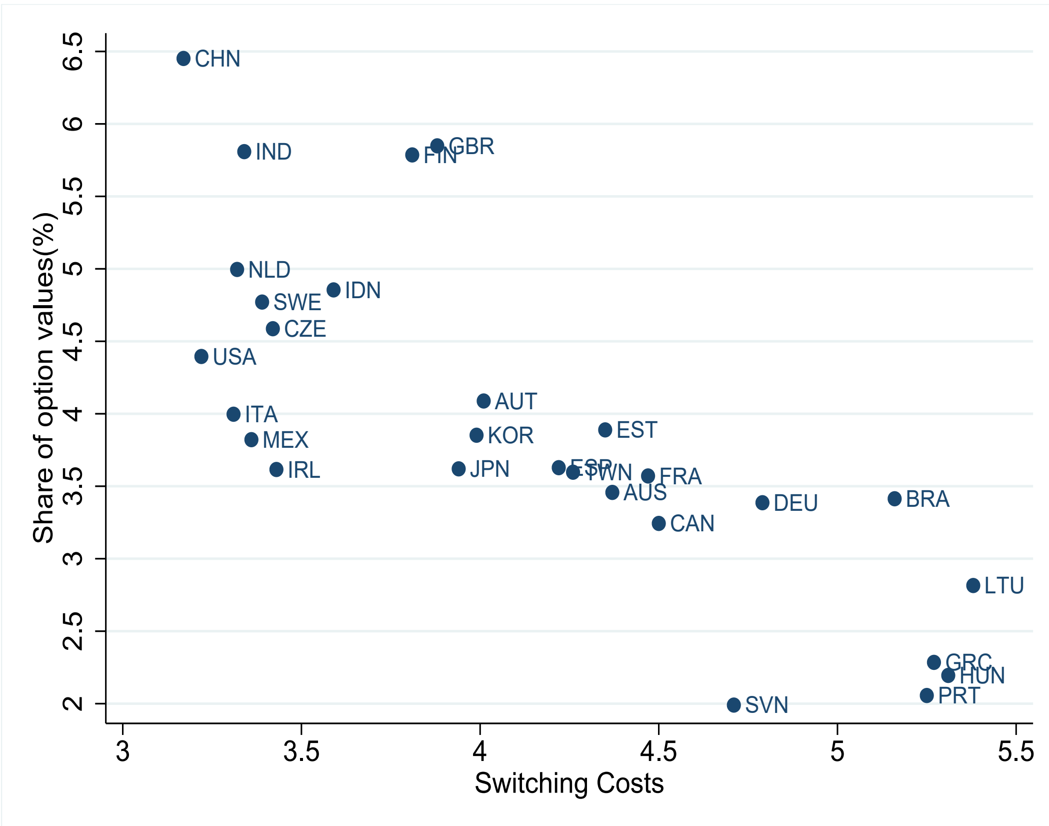

Figure B.7: The Share of Option Values in Welfare Gains from Trade

Notes: The option value is calculated with equation (2.27).

Table B.1: Mean Wage by Sector

Sector	Wage	Sector	Wage
Agriculture	1.00	Other manufacturing	1.63
Textiles	1.40	Machinery	2.47
Wood and paper	2.12	Transport service	2.77
Chemicals and fuels	3.14	Transport equipment	2.95
Metals	2.79	FIRE	3.41

Source: Święcki (2017b)

Table B.2: Estimates of Switching Costs

Country	Switching Costs	Country	Switching Costs
Australia	4.37^{**}	Ireland	3.43^{**}
Austria	4.01^{**}	Italy	3.31^{*}
Brazil	5.16^{**}	Japan	3.94^{**}
Canada	4.50^{**}	Korea	3.99^{*}
China	3.17^{*}	Lithuania	5.38^{**}
Czechia	3.42^{**}	Mexico	3.36^{**}
Denmark	3.65^{**}	Netherland	3.32^{**}
Estonia	4.35^{*}	Portugal	5.25^{**}
Finland	3.81^{**}	Romania	4.18^{*}
France	4.47^{**}	Slovenia	4.71^{**}
Germany	4.79^{**}	Spain	4.22^{**}
Greece	5.27^{**}	Sweden	3.39^{**}
Hungary	5.31^{**}	Taiwan	4.26^{**}
India	3.34^{**}	United Kingdom	3.88^{**}

Note: **, * represent 99% and 95% significancy level, respectively. Standard errors are calculated using the properties of minimum distance estimator.

Table B.3: Comparison with Labor Market Flexibility Measure

L.Country	SWC	Flexibility	H.Country	SWC	Flexibility
China	3.17	70	USA	3.22	97
India	3.34	52	Netherland	3.32	57
Indonesia	3.59	43	United Kingdom	3.88	80
			Korea	3.99	66
M.Country			Austria	4.01	83
Czechia	3.42	72	Australia	4.37	83
Estonia	4.35	56	France	4.47	34
Brazil	5.16	28	Slovenia	4.71	47
Hungary	5.31	60	Germany	4.79	45
Lithuania	5.38	59	Portugal	5.25	42

Source: Cunat and Melitz (2012). Here, low income countries are countries with GDP per capita lower than $5,000, middle income countries are with $5,000 ~ $10,000, and high income countries are with more than $10,000.

Table B.4: Estimation of the Productivity Dispersion

sector	θ^j	s.e.	95% C.I.
capital goods	0.21	0.03	(0.16, 0.27)
non-capital goods	0.18	0.02	(0.14, 0.22)

Note: The robust standard errors are reported and the confidence interval is calculated using the standard errors.

APPENDIX C

CALIBRATION OF ν

Recall that the switching cost estimation equation in ACM (2010) was as follows:

$$(\ln m_t^{j,k} - \ln m_t^{j,j}) = -\frac{(1-\beta)}{\nu}\tau^{j,k} + \frac{\beta}{\nu}(\ln w_{t+1}^k - \ln w_{t+1}^j) + \beta(\ln m_{t+1}^{j,k} - \ln m_{t+1}^{k,k}) + \xi_{t+1}^{j,k} \quad (2.13)$$

From this equation, the level of gross flow of labor identifies τ/ν (for a given β), and $1/\nu$ captures the elasticity of gross flows with respect to the expected future wage differentials. Intuitively, if the variance of idiosyncratic preference shock increases, workers care more about their preferences and are less responsive to the wage differentials.

One concern is that I can only observe the net flow of labor allocations and wages. As discussed in section 3.1, if I observe persistent wage differentials, but workers do not move toward the high wage-paying sector, the estimation algorithm assigns higher switching costs. To ensure the estimator work, I need to normalize ν because the labor flows are also associated with the elasticity.

CDP (2019) estimates ν by adopting the same method and data as in ACM (2010). With a yearly discount factor β of roughly 0.96,[1] they suggest that the inverse elasticity of labor flows is 2.02. This normalization implies that idiosyncratic preference does not differ across countries while the common switching costs τ vary depending on the countries' labor market conditions. It is not a too strong assumption, and therefore, I focus on estimating switching cost to conduct the comparative cross-country analysis in evaluating the welfare gains from trade.

[1]They use quarterly data, and the corresponding discount factor is 0.99.

APPENDIX D

STANDARD ERROR OF τ

The asymptotic distribution of τ can be obtained following the standard properties of the minimum distance estimator. [1] First, define $\tilde{\Lambda}^j_{t+1} \equiv \tilde{L}_{t+1}(\hat{\tau}) - \tilde{L}_t(\hat{\tau})$ be the model generated labor dynamics and $\Lambda^j_{t+1} \equiv L_{t+1} - L_t$ be the observed labor dynamics. Note that only $\tilde{\Lambda}^j_{t+1}$ is dependent on the minimizing argument $\hat{\tau}$. Recall that the minimum distance problem is:

$$\hat{\tau} = argmin \sum_{j,t}((\tilde{L}^j_{t+1} - \tilde{L}^j_t) - (L^j_{t+1} - L^j_t))^2$$

The first order condition of the problem implies that:

$$\frac{1}{n}\sum_{j,t}\hat{g}^j_{t+1} = 0 \quad where \quad \hat{g}^j_{t+1} \equiv \frac{\partial\hat{\Lambda}^j_{t+1}}{\partial\tau}\left[\Lambda^j_{t+1} - \hat{\Lambda}^j_{t+1}(\tau)\right]$$

A mean value expansion of the above equation around the true value τ_0 implies:

$$\frac{1}{n}\sum_{j,t} g^j_{t+1} + \frac{1}{n}\sum_{j,t}\frac{\partial g^j_{t+1}}{\partial\tau}(\hat{\tau} - \tau) = 0$$

Under the regularity conditions for the consistency of the minimum distance estimator:

$$\begin{aligned}
\sqrt{n}(\hat{\tau} - \tau) &= -\left[\frac{1}{n}\sum_{j,t}\frac{\partial g^j_{t+1}}{\partial\tau}\right]^{-1}\frac{1}{\sqrt{n}}\sum_{j,t} g^j_{t+1} \\
&\rightarrow N\Big(0, \left[\frac{1}{n}\sum_{j,t}\frac{\partial g^j_{t+1}}{\partial\tau}\right]^{-1}(\frac{1}{n}\sum_{j,t}(g^j_{t+1})^2)\left[\frac{1}{n}\sum_{j,t}\frac{\partial g^j_{t+1}}{\partial\tau}\right]^{-1}\Big)
\end{aligned}$$

[1] ALP (2015) also provides algebraic derivation of the asymptotic distribution of their estimator.

APPENDIX E

PROOF OF PROPOSITIONS

In this section, I present the algebraic derivation of Proposition 1 and 2. As defined in the main text, for variable x, $\dot{x}$ is defined as $\dot{x}_{t+1} \equiv \frac{x_{t+1}}{x_t}$.

Proposition 1 The derivation begins from equation (2.5). Since B^j is a constant, this term will cancel out when the equation is transformed to the relative time difference form. Specifically, the unit cost equation is multiplicative, it can be simply written in 'dot' form as follows:

$$\dot{x}^j_{t+1} = \dot{z}^j_{t+1}\left[(\dot{r}_{t+1})^{\xi}(\dot{w}^j_{t+1})^{1-\xi}\right]^{\gamma^j}\prod_{k\in J}(\dot{P}^k_{t+1})^{\gamma^{k,j}} \tag{2.14}$$

From equation (2.8):

$$\dot{P}^j_{t+1,n} = \frac{P^j_{t+1,n}}{P^j_{t,n}} = \frac{\Psi^j(\sum_{i\in I}\lambda^j_i[x^j_{t+1,i}\kappa^j_{t+1,ni}]^{-\theta^j})^{-1/\theta^j}}{\Psi^j(\sum_{i\in I}\lambda^j_i[x^j_{t,i}\kappa^j_{t,ni}]^{-\theta^j})^{-1/\theta^j}}$$

By multiplying and dividing each term in the numerator by $\lambda^j_i[x^j_{t+1,i}\kappa^j_{t+1,ni}]^{-\theta^j}$:

$$\dot{P}^j_{t+1,n} = \left[\frac{\sum_{i\in I}\lambda^j_i(x^j_{t,i}\kappa^j_{t,ni})^{-\theta^j}(\frac{x^j_{t+1,i}\kappa^j_{t+1,ni}}{x^j_{t,i}\kappa^j_{t,ni}})^{-\theta^j}}{\sum_{i\in I}\lambda^j_i(x^j_{t,i}\kappa^j_{t,ni})^{-\theta^j}}\right]^{-1/\theta^j}$$

Then, by the definition of $\pi^j_{t,ni}$ in equation (2.9):

$$\dot{P}^j_{t+1,n} = \left[\sum_{j\in J}\pi^j_{t,ni}(\dot{x}^j_{t+1,i}\dot{\kappa}^j_{t+1,ni})^{\theta^j}\right]^{-1/\theta^j} \tag{2.15}$$

Similarly, by multiplying and dividing each term both in the numerator and denominator of equation (2.9) by $x^j_{t,i}\kappa^j_{t,i}$ leads to the following:

$$\frac{\lambda^j_i(x^j_{t,i}\kappa^j_{t,ni})^{-\theta^j}(\dot{x}^j_{t+1,i}\dot{\kappa}^j_{t+1,ni})^{-\theta^j}}{\sum_{i\in I}\lambda^j_i(x^j_{t,i}\kappa^j_{t,ni})^{-\theta^j}(\dot{x}^j_{t+1,i}\dot{\kappa}^j_{t+1,ni})^{-\theta^j}}$$

Then, by dividing numerator and denominator by $\sum_{i\in I} \lambda_i^j (x_{t,i}^j \kappa_{t,ni}^j)^{-\theta^j}$:

$$\frac{\frac{\lambda_i^j (x_{t,i}^j \kappa_{t,ni}^j)^{-\theta^j}}{\sum_{i\in I} \lambda_i^j (x_{t,i}^j \kappa_{t,ni}^j)^{-\theta^j}} (\dot{x}_{t+1,i}^j \dot{\kappa}_{t+1,ni}^j)^{-\theta^j}}{\frac{\sum_{i\in I} \lambda_i^j (x_{t,i}^j \kappa_{t,ni}^j)^{-\theta^j} (\dot{x}_{t+1,i}^j \dot{\kappa}_{t+1,ni}^j)^{-\theta^j}}{\sum_{i\in I} \lambda_i^j (x_{t,i}^j \kappa_{t,ni}^j)^{-\theta^j}}} = \frac{\pi_{t,ni}^j (\dot{x}_{t+1,i}^j \dot{\kappa}_{t+1,ni}^j)^{-\theta^j}}{\sum_{i\in I} \pi_{t,ni}^j (\dot{x}_{t+1,i}^j \dot{\kappa}_{t+1,ni}^j)^{-\theta^j}}$$

The equality holds by the the definition of $\pi_{t,ni}^j$ in equation (2.9). Note that the denominator of the above equation is equal to the relative time difference form of composite price as in equation (2.15). Finally, equation (2.16) is obtained as follows:

$$\pi_{t+1,ni}^j = \pi_{t,ni}^j \left(\frac{\dot{x}_{t+1,i}^j \dot{\kappa}_{t+1,ni}^j}{\dot{P}_{t+1}^j} \right)^{-\theta^j} \tag{2.16}$$

Note that $w_{t+1,i}^j L_{t+1,i}^j = \dot{w}_{t+1,i}^j \dot{L}_{t+1,i}^j w_{t,i}^j L_{t,i}^j$ by the definition of *dot* operator. In addition, recall that investment rate is defined as $\rho_{t,i} \equiv= \frac{P_{t,i}^C I_{t,i}}{r_{t,i} K_{t,i}}$. Then, the derivation of equations (2.22) - (2.19) is straightforward.

Proposition 2 For the proof of Proposition 2, I begin with equation (2.3):

$$\frac{\mu_t^{j,k}}{\mu_{t-1}^{j,k}} = \frac{\frac{\exp(\beta V_{t+1}^k - \tau^{j,k})^{1/\nu}}{\sum_{l\in J} \exp(\beta V_{t+1}^l - \tau^{j,k})^{1/\nu}}}{\frac{\exp(\beta V_t^k - \tau^{j,k})^{1/\nu}}{\sum_{l\in J} \exp(\beta V_t^l - \tau^{j,k})^{1/\nu}}} = \frac{\frac{\exp(\beta V_{t+1}^k - \tau^{j,k})^{1/\nu}}{\exp(\beta V_t^k - \tau^{j,k})^{1/\nu}}}{\frac{\sum_{l\in J} \exp(\beta V_{t+1}^l - \tau^{j,k})^{1/\nu}}{\sum_{l\in J} \exp(\beta V_t^l - \tau^{j,k})^{1/\nu}}}$$

Recall that the switching costs are assumed to be symmetric $\tau^{j,k} = \tau \ \forall \ j,k \in J$, and τ is time-invariant. Then, by the property of exponential function, the above equation can be simplified as follows:

$$\frac{\mu_t^{j,k}}{\mu_{t-1}^{j,k}} = \frac{\exp(\beta V_{t+1}^k - \beta V_t^k)^{1/\nu}}{\frac{\sum_{l\in J} \frac{\exp(\beta V_{t+1}^k - \tau)^{1/\nu}}{\exp(\beta V_t^k - \tau)^{1/\nu}} \exp(\beta V_t^l - \tau)^{1/\nu}}{\sum_{l\in J} \exp(\beta V_t^l - \tau)^{1/\nu}}} = \frac{\exp(\beta V_{t+1}^k - \beta V_t^k)^{1/\nu}}{\sum_{l\in J} \mu_{t-1}^{j,l} \exp(\beta V_{t+1}^l - \beta V_t^l)^{1/\nu}}$$

Following the notational assumption $u_t^j \equiv exp(V_t^j)$, equation (2.20) can be obtained as follows:

$$\mu_t^{j,k} = \frac{\mu_{t-1}^{j,k} (\dot{u}_{t+1}^k)^{\beta/\nu}}{\sum_{l\in J} \mu_{t-1}^{j,l} (\dot{u}_{t+1}^l)^{\beta/\nu}} \tag{2.20}$$

The derivation of equation (2.21) begins from equation (2.2).

$$V_{t+1}^{j} - V_t^{j} = U(C_{t+1}^{H,j}) - U(C_t^{H}, j) + \nu \log[\sum_{k\in J} \exp(\beta V_{t+2}^{k} - \tau)^{1/\nu}] - \nu \log[\sum_{k\in J} \exp(\beta V_{t+1}^{k} - \tau)^{1/\nu}]$$
$$= U(C_{t+1}^{H,j}) - U(C_t^{H,j}) + \nu log \left[\frac{\sum_{k\in J} \exp(\beta V_{t+2}^{k} - \tau)^{1/\nu} \frac{\exp(\beta V_{t+1}^{k} - \tau)^{1/\nu}}{\exp(\beta V_{t+1}^{k} - \tau)^{1/\nu}}}{\sum_{k\in J} \exp(\beta V_{t+1}^{k} - \tau)^{1/\nu}} \right]$$

Since $\mu_t^{j,k} = \frac{\exp(\beta V_{t+1}^{k} - \tau)^{1/\nu}}{\sum_{k\in J} \exp(\beta V_{t+1}^{k} - \tau)^{1/\nu}}$,

$$V_{t+1}^{j} - V_t^{j} = U(C_{t+1}^{H,j}) - U(C_t^{H}, j) + \nu \log \left[\sum_{k\in J} \mu_t^{j,k} \exp(\beta V_{t+2}^{k} - \beta V_{t+1}^{k})^{1/\nu} \right]$$

By taking exponential on both sides of the above equation:

$$\dot{u}_{t+1}^{j} = \dot{\omega}_{t+1}^{j} (\mu_t^{j,k} (\dot{u}_{t+2}^{k})^{\beta/\nu})^{\nu} \tag{2.21}$$

where $C_t^{H,j} = \frac{w_t^j}{P_t}$ and $\omega_t^j \equiv \frac{w_t^j}{P_t}$.

Note that the derivation of equation (2.23) is straightforward from $\rho_t \equiv \frac{P_t^C I_t}{r_t K_t}$.

The last step is the Euler equation of rentier's (2.24). Recall that $U(C_t^R) = \log C_t^R$ and $P_t C_t^R = (1 - \rho_t) r_t K_t$. Then, from equation (2.6) the following holds:

$$\frac{C_{t+1}^R}{C_t^R} = \beta \frac{P_t}{P_{t+1}} \left[\frac{r_{t+1}}{P_t^C} + P_{t+1}^C (1 - \delta) \right]$$

It can be re-written as follows:

$$\frac{(1 - \rho_{t+1})}{(1 - \rho_t)} \dot{r}_{t+1} \dot{K}_{t+1} = \beta \left[\frac{\dot{r}_{t+1} r_t}{P_t^C} + \dot{P}_{t+1}^C (1 - \delta) \right] \tag{E.1}$$

Note that from the definition of investment rate the following holds:

$$\frac{P_t^C}{r_t} \frac{I_t}{K_t} = \frac{P_t^C}{r_t} \frac{K_{t+1} - (1 - \delta) K_t}{K_t} = \frac{P_t^C}{r_t} \{ \dot{K}_{t+1} - (1 - \delta) \} = \rho_t$$

Thus, by plugging-in $\frac{r_t}{P_t^C} = \frac{\dot{K}_{t+1}-(1-\delta)}{\rho_t}$ into the above equation:

$$\frac{1-\rho_{t+1}}{1-\rho_t}\dot{r}_{t+1}\dot{K}_{t+1} = \beta\left[\dot{r}_{t+1}\left(\frac{\dot{K}_{t+1-(1-\delta)}}{\rho_t}\right) + \dot{P}_{t+1}^C(1-\delta)\right] \tag{2.24}$$

APPENDIX F

WELFARE GAINS FROM TRADE AND OPTION VALUE

Option Value Recall that the expected lifetime value of being employed at sector k at time t follows equation (2.2):[1]

$$V_t^k = U(C_t^H) + \nu \log[\sum_{j \in J} exp(\beta V_{t+1}^j - \tau^{k,j})^{1/\nu}] \tag{2.2}$$

By adding and subtracting βV_{t+1}^k the above equation can be re-written as follows:

$$V_t^k = U(C_t^H) + \beta V_{t+1}^k + \nu \log[\sum_{j \in J} exp(\beta(V_{t+1}^j - V_{t+1}^k) - \tau^{k,j})^{1/\nu}] \tag{2.2-1}$$

Since the fraction of the workers staying their employed sector is given by equation (2.3) as follows:

$$\mu_t^{k,k} = \frac{exp(\beta V_{t+1}^k)^{1/\nu}}{\sum_{l \in J} exp(\beta E_t V_{t+1}^l - \tau^{j,l})^{1/\nu}}$$

The option value in equation (2.2-1) can be obtained as:

$$\nu \log[\sum_{j \in J} exp(\beta(V_{t+1}^j - V_{t+1}^k) - \tau^{k,j})^{1/\nu}] = -\nu \log \mu_t^{k,k}$$

By plugging in the result into equation (2.2-1), the value function of workers can be simplified to:

$$V_t^k = U(C_t^H) + \beta V_{t+1}^k - \nu \log \mu_t^{k,k} \tag{2.2-2}$$

In addition, the value function can be expressed as the present value discounted summation of consumption path as follows:

$$\begin{aligned} V_t^k &= \frac{1}{1-\beta} U(C_t^H) - \frac{1}{1-\beta} \nu \log \mu_t^{k,k} \\ &= \sum_{s=t}^{\infty} \beta^{s-t} U(C_t^H) - \nu \sum_{s=t}^{\infty} \beta^{s-t} \log \mu_t^{k,k} \\ &= \sum_{s=t}^{\infty} \beta^{s-t} \log \left[\frac{C_s^{H,j}}{(\mu_s^{j,j})^{\nu}} \right] \end{aligned}$$

[1] For simplicity, I ignore the expectation operator because $E_t[V_t] = V_t$ as discussed in section 3.1.

Gains from Trade If I define V_t^k and $V_t'^k$ to be the value of being employed in sector k at time t under a counterfactual scenario (i) and (ii), the welfare gains from trade are the compensation variation in consumption in sector k at time t (η^j):

$$V_t'^k = V_t^k + \sum_{s=t}^{\infty} \beta^{s-t} \log(\eta^k)$$

Similar to above, this implies:

$$\begin{aligned}
\log(\eta^k) &= (1-\beta)(V_t'^k - V_t^k) \\
&= (1-\beta) \sum_{s=t}^{\infty} \beta^{s-t} \log \left[\frac{C_s'^{H,j} / C_s^{H,j}}{(\mu_s'^{j,j} / \mu_s^{j,j})^{\nu}} \right] \\
&= \sum_{s=t}^{\infty} \beta^{s-t} \log \left[\frac{C_s'^{H,j} / C_s^{H,j}}{(\mu_s'^{j,j} / \mu_s^{j,j})^{\nu}} \right] - \sum_{s=t}^{\infty} \beta^{s+1-t} \log \left[\frac{C_s'^{H,j} / C_s^{H,j}}{(\mu_s'^{j,j} / \mu_s^{j,j})^{\nu}} \right] \\
&= \log \left[\frac{C_0'^{H,j} / C_0^{H,j}}{(\mu_0'^{j,j} / \mu_0^{j,j})^{\nu}} \right] + \sum_{s=t+1}^{\infty} \beta^{s-t} \log \left[\frac{(C_s'^{H,j} / C_s^{H,j}) / (C_{s-1}'^{H,j} / C_{s-1}^{H,j})}{\{(\mu_s'^{j,j} / \mu_s^{j,j}) / (\mu_{s-1}'^{j,j} / \mu_{s-1}^{j,j})\}^{\nu}} \right] \\
&= \log \left[\frac{C_0'^{H,j} / C_0^{H,j}}{(\mu_0'^{j,j} / \mu_0^{j,j})^{\nu}} \right] + \sum_{s=t+1}^{\infty} \beta^{s-t} \log \left[\frac{\hat{C}_s'^{H,j}}{(\hat{\mu}_s'^{j,j})^{\nu}} \right]
\end{aligned}$$

Note that at 2006, that is the initial t to begin the counterfactual analysis, $C_0'^{H,j} = C_0^{H,j}$ and $\mu_0'^{j,j} = \mu_0^{j,j}$. Thus, the first term on the right-hand side cancel out, and the welfare measure can be written as equation (2.27):

$$\log(\eta^j) = \sum_{s=t+1}^{\infty} \beta^{s-t} \log \left[\frac{\hat{C}_s^j}{(\hat{\mu}_s^{j,j})^{\nu}} \right] \quad where \ \hat{C} \equiv \dot{C}' / \dot{C}$$

APPENDIX G

ALGORITHM TO SOLVE THE GENERAL EQUILIBRIUM MODEL

This is the algorithm I used to solve the general equilibrium model. As discussed in section 3.2.1, the algorithm is composed of 3 steps. The first step involves guessing the sequence of investment expenditure in order to generate the sequence of the capital stock. In the second step I guess the sectoral value functions of workers. With this conjecture in hand, I can calculate the gross labor flows and generate the labor market dynamics. Finally, for the given sequence of factor allocations, the model is solved for each t following the results derived in Proposition 1.

(1-1) Guess $\{I_{t+1}\}_{t=0}^{\infty}$

(1-2) Get $\{\dot{I}_{t+1}\}_{t=0}^{\infty}$ using I_0

(1-3) Given K_0, get $\{\dot{K}_{t+1}\}_{t=0}^{\infty}$ using $K_{t+1} = (1-\delta)K_t + I_t$

- (2-1) Guess $\{\dot{u}_{t+1}\}_{t=0}^{\infty}$
- (2-2) Generate $\{\dot{\mu}_{t+1}\}_{t=0}^{\infty}$ with μ_{-1} and equation (2.20)
- (2-3) Generate $\{\dot{L}_{t+1}\}_{t=0}^{\infty}$ with L_0 and equation (2.22)
  - (3-1) Guess $\{\dot{w}_{t+1}\}_{t=0}^{\infty}$
  - (3-2) Solve for $\{\dot{x}_{t+1}\}_{t=0}^{\infty}$, $\{\dot{P}_{t+1}\}_{t=0}^{\infty}$, $\{\pi_{t+1}\}_{t=0}^{\infty}$
  - (3-3) Get $\{\dot{\rho}_{t+1}\}_{t=0}^{\infty}$ using equation (2.21)
  - (3-4) Solve for $\{\dot{X}_{t+1}\}_{t=0}^{\infty}$
  - (3-5) Check labor market clearing condition. If not, go back to (3-1) and update the guess of wages
- (2-4) With $\{\dot{w}_{t+1}, \dot{r}_{t+1}, \dot{P}_{t+1}\}_{t=0}^{\infty}$ check equation (2.21). If not, update the guess of $\{\dot{u}_{t+1}\}_{t=0}^{\infty}$

(1-4) Check Euler equation (2.24). If not, update the guess of $\{I_{t+1}\}_{t=0}^{\infty}$

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